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Title: **Japanese Style Networks and Innovations in High-Technology Firms in Texas**

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Abstract:

Discusses U.S.-Japanese competitiveness and how it might affect policy and the high-technology industry. Describes Japanese knowledge and spatial networks with a focus on their contribution to innovations. Discusses previous studies on the high-tech industry, highlighting the strengths and weaknesses of different criteria used to classify firms as high-tech firms. Discusses an analysis of employment trends in the main high-tech regions in the U.S. Applies a new classification of high-tech establishments for study and presents the results from an empirical analysis of the contribution of knowledge networks and spatial proximity to the innovation performance of high-tech firms in Texas. Argues that policies designed to enhance regional development through innovation should take into account whether local or non-local knowledge linkages are more significant for innovation.

Keywords: high tech; policy; innovation; competitiveness; knowledge networks; spatial networks; Texas

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Japanese Style Networks and Innovations in High-Technology Firms in Texas

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Introduction

According to the March 5, 1997 issue of the *Wall Street Journal,* Texas passed New York to claim the number two ranking in high-tech jobs.[1] The newspaper cited statistics, recently published by the American Electronic Association, that show 313,460 Texans employed in high-tech jobs in 1995, trailing only California's 669,349. The high-tech work force in Texas increased by 39,000 jobs from 1990 to 1995, the biggest leap in the nation. The state, however, remains third behind New York and California in the number of high-tech businesses and total payroll.

Twenty years ago, the Texas energy sector made headlines in major newspapers. Today, high technology (both manufacturing and services) rivals the energy sector as the engine of growth of the state (Petersen and Thomas 1995). Employment data show that while the energy sector employed 260,000 people in Texas in 1980 (accounting for 4.3 percent of total nonagricultural employment in the state), only 156,000 worked in that sector in 1996 (accounting for 1.8 percent of total nonagricultural employment in the state). The oil and gas extraction industry accounts for a larger share of state output than of total state employment. Duca (1997), an economist with the Federal Reserve Bank of Dallas, points out that high tech[2] accounts for 20 percent of the state's economic output, while energy accounts for around 10 percent.

With this change in the economy has come a change in emphasis in economic and business discussions. The economic and business issues of the 1980s concerned the price of oil and the exploration of new oil reserves, but the relevant issues of the 1990s focus on the competitiveness of high-technology firms, which, in many sectors, is defined by competition with Japanese firms (see Tyson 1993). The National Science Foundation (1996) reports that between 1983 and 1993 (the latest year for which this information is available), the number of U.S. patents granted to Japanese residents increased dramatically, with Japanese investors receiving 23 percent of all

[1] High tech is defined as computer and office equipment, consumer electronics, communications equipment, electronic components and accessories, semiconductors, and industrial electronics.

[2] He uses a definition of high technology that includes sectors that have a higher percentage of technicians, engineers, and scientists than most manufacturers and that have an above-average research and development component.

U.S. patents in 1993 and 49 percent of all U.S. patents with foreign origin. Only ten years earlier, these shares were 16 and 37 percent, respectively. In nearly all of the six commercially important industries—computer hardware, industrial machinery, radio and television equipment, electronics, automobiles, and aircraft—Japanese investors quickly narrowed the gap with the United States during the 1980s.

Competitiveness and Networks: The Example of the Japanese Auto Industry

To understand U.S.–Japanese industrial competitiveness and how it might affect the high-tech industry, policymakers should look to the automobile industry. No industry better illustrates this issue. And no firm more closely represents the strategies associated with a successful Japanese firm than Toyota. The "Toyota system" has been widely emulated by automobile firms and by firms in other highly competitive industries.[3] Data on the Japanese automobile industry reveal that Japan's share of world auto production increased from 2.9 percent in 1960 to 29.7 percent in 1982. In that year, the Japanese auto industry was the world's largest, capturing 19.2 percent of the U.S. market (Echeverri-Carroll 1994).

The preeminence of the Japanese automobile industry prompted the Massachusetts Institute of Technology to create the International Motor Vehicle Program[4] (IMVP) to study and identify the characteristics of a "successful" automobile firm. The MIT studies, as well as other studies outside the program,[5] cite the *creation of networks* with suppliers, customers, and other organizations as one of the most important components of the Japanese industrial organization. Of course, not all firms will benefit from Japanese-style networks. As Aoki (1986) points out, such networks seem to work best in industries that are marked by continuously changing demand

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[3] A good account of the success of Japanese automobile and electronics firms against U.S. competitors is found in Dertouzos, Lester, and Solow (1989) and Forester (1993).

[4] The International Motor Vehicle Program at MIT was created in 1985 with the objective of conducting studies to help revitalize the U.S. automobile industry. By 1990, the program had published more than 116 monographs. Most of the findings of these studies were summarized in a book titled *The Machine That Changed the World* by Womack et al., published in 1990.

[5] See Altschuler 1985; Cusumano 1985; Cusumano and Takeishi 1991; Dankbaar 1992; Helper 1989, 1990, 1991, 1993; Helper and Sako 1995; Krafcik 1987; Krafcik and MacDuffie 1989; Lamming 1987; Minato 1991; Nishiguchi 1987, 1994; Shimokawa 1982; and Womack et al. 1990.

conditions and associated needs for continual adjustment in task coordination. These characteristics define competition in high-tech firms.

How do we define networks? Susan Helper, who directs the IMVP studies on supplier–customer relationships, distinguishes between *arm's length* supply systems, which characterize the "traditional" American firm, and *voice* relationships (that we use as a proxy for network systems), which characterize the Japanese firm.[6] Arm's-length relationships are short-term and involve little exchange of information between firms. In contrast, network systems are based on long-term relationships between firms, significant information exchange, joint problem solving, and governance by trust.[7]

Networks and Innovation

We argue, following Aoki (1986, 1990) and Sako and Helper (1997), that the significant knowledge exchange that characterizes Japanese-style networks exercises a positive influence on innovations. Knowledge is a key input in both the *development* of new products and processes and the *speed* at which they are introduced. As Feldman (1994) notes, commercially viable product innovations combine scientific and technical knowledge with knowledge of the market. The importance of knowledge for innovations is also recognized by Dosi (1988), who posits that innovation is perhaps best characterized as an intrinsically uncertain problem-solving process that blends private knowledge with public knowledge. Private knowledge comes primarily from within the firm while public knowledge is found in industry associations, scientific and professional societies, and networks of related firms and support services (Nelson 1988).

It could also be argued that the locational patterns of Japanese firms produce a positive effect on innovations. A good example of the geographical patterns usually associated with

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[6] Helper regularly surveys automobile suppliers in the United States to measure the extent to which they are implementing Japanese network systems. She finds that although there has been real progress by U.S. auto parts producers, many of the changes in the relationship between suppliers and customers in the U.S. automobile industry have come at the suppliers' expense.

[7] A good summary of the literature on contrasts between arm's length and Japanese-style relationships is found in Echeverri-Carroll (1994, 1996).

Japanese firms is found in the Japanese automobile industry. Auto assembly, especially parts production, in Japan is heavily concentrated in the core industrial region of Keihin (Tokyo–Yokohama) and around Nagoya City (Sheard 1983). This same clustering pattern has been observed among Japanese automobile companies in the United States: Japanese transplant suppliers are concentrated mainly in the lower Midwest and upper South, in the same states that house transplant assembly facilities (Mair et al. 1988; Glasmeier and McCluskey 1987; Kenney and Florida 1992).

But what is the relationship between spatial proximity and innovations? Spatial proximity affects innovations in two ways. First, as anticipated by Krugman (1991), it reduces the costs of communication between firms.[8] Cheaper communication creates incentives for more frequent contacts that result in an increasing exchange of knowledge. As noticed by Audretsch and Feldman (1996), the cost of transmitting *knowledge* increases with distance, even though the cost of transmitting *information* may be invariant to distance. Second, spatial proximity enhances knowledge spillovers. Firms cannot appropriate all the knowledge that they generate; therefore, some of their knowledge spills over to other firms. Because other firms do not pay for this knowledge, it is a knowledge externality. As Powell et al. (1996) point out, knowledge is difficult to capture inside the boundaries of an organization: most of the know-how is neither located inside an organization nor readily available for purchase.

Innovative activities therefore provide firms with an incentive to concentrate geographically to capture knowledge not only from other firms (including suppliers and customers), but also from local organizations such as universities and business services (Feldman 1994). Indeed, the success of firms in developing new products and processes may be associated with the intensity of their communication with local firms. Saxenian (1994), for instance, points out that although firms in network systems serve global markets and collaborate with distant customers, suppliers, and competitors (technology firms, in particular, are highly international),

[8] Although other authors recognize that locational patterns of auto suppliers close to the final assembly has given Japanese automobile firms a competitive advantage over U.S. firms (Cusumano 1985; Womack et al. 1990; Dyer 1996), most of these advantages have not been associated with their innovative performance.

the most strategic relationships are often local. Timeliness and face-to-face communication are critical for rapid product development.

What This Means for the High-Tech Industry

Because high-technology industries employ a far greater proportion of scientists and engineers than other industries (Markusen et al. 1986), it is natural to assume that high-tech firms are highly localized because of the positive effects on innovations that result from a high local exchange of ideas. It could be argued, in this context, that the spatial agglomeration of suppliers and customers that characterizes Japanese firms could give them competitive advantages in the development of new products and processes. But this advantage is not unique to Japanese high-technology firms. In fact, Krugman (1991) notes that the fame of such clusters as California's Silicon Valley and Boston's Route 128[9] have made the exchange of technical information one of the primary reasons for high-tech firms to agglomerate.

Malecki (1991) notes that high-technology firms are relatively concentrated in a few spatial clusters; however, the exchange of technical information may not necessarily be their main reason for concentrating. Marshall (1920) suggests that knowledge exchange is only one reason why firms in the same industry agglomerate; a pooled market of workers with specialized skills and the availability of specialized inputs are also important agglomerative forces. Accordingly, Krugman (1991) and Head et al. (1995) suggest that knowledge exchange is not always the typical reason for spatial agglomeration, even in high-technology industries. In fact, Krugman (1991) argues that high-technology firms agglomerate for reasons similar to those of non-high-technology firms. Silicon Valley, of course, is famous, but Krugman cites the equally remarkable concentrations to be found among carpet producers around Dalton, Georgia; jewelry producers around Providence, Rhode Island; and financial services in New York. Forces for localization other than those involving knowledge spillovers are evidently quite strong. Moreover, knowledge

[9] The 27-mile stretch of the Route 128 highway links some 20 towns in the greater Boston area and provides a prestigious and attractive location for technology firms—one that is ideally situated within a short drive of MIT, Cambridge, and several desirable suburban communities.

may be more expensive to transfer than information, but it may also benefit companies more than information, especially in terms of the positive effects that knowledge has on innovations. This may provide companies with an incentive to look for knowledge outside the city, thus capturing knowledge spillovers by maintaining strong *external* relationships.

This Study

Previous studies defined industries as high tech if the percentage of engineers and scientists employed exceeds that of the U.S. manufacturing industry as a whole. The main drawback of this definition is that different establishments *within* an industry may use different degrees of technology in their production processes. Thus, while some establishments may be high tech, it may not be accurate to label the entire industry high tech. To avoid this problem, we asked *each establishment* in our sample what percentage of its labor force is represented by engineers and scientists. Based on this information, we classified our sample into two groups of establishments. Those in which at least 6 percent of their total employees are engineers and scientists we call *high-tech establishments,* and those with a proportion of engineers and scientists less than 6 percent we call *non-high-tech establishments.*

Our study identifies and explains patterns of relationships and location in high-technology establishments and their effect on innovations. Specific questions include: How can a city attract innovative high-technology firms? How can a city attract high- instead of non-high-technology firms? How can Texas high-technology firms speed up their product and process innovations? In the process of developing new products and processes, do high-technology firms establish relationships mainly with local customers and suppliers? How can a large university have a positive effect on high-tech firms' innovations?

These questions should be of interest to local policymakers and high-technology firms. Policies designed to enhance regional development through innovation should take into account whether local or non-local knowledge linkages are more significant for innovation. If linkages within a given region are more important for a firm's innovative performance, policymakers will be more interested in providing venues for local firms to meet and share information. However, if external linkages are more relevant, policymakers should focus on providing better communication to and from the area, including an airport that can provide frequent flights for skilled labor. The results of this study should also be of interest to Texas firms, especially those that are less innovative, by providing suggestions on what kinds of linkages are more important for improving their innovation performance.

The report is divided into several sections. Section 1 reviews the literature on Japanese knowledge and spatial networks with a focus on their contribution to innovations. Section 2 reviews previous studies on the high-technology industry, highlighting the strengths and weaknesses of different criteria used to classify firms as high-technology firms. Section 3 analyzes employment trends in the main high-technology regions in the United States, including five regions within Texas. Section 4 presents results from an empirical analysis of the contribution of knowledge networks and spatial proximity to the innovation performance of high-technology firms in Texas. The analysis is based on 23 interviews conducted with high-technology firms in the five largest metropolitan areas in Texas and on the results of a survey mailed to 1,772 high-technology manufacturing firms in the same metropolitan areas. Section 5 presents conclusions from the analysis.

Section 1
The Japanese Model: Knowledge and Spatial Networks

Collaboration enhances firms' learning and provides them with timely access to knowledge and resources that are otherwise unavailable, while it also tests firms' internal expertise and learning capabilities (Hamel 1991; Dodgson 1993; Powell et al. 1996; Mowery and Rosenberg 1989; Arora and Gambardella 1994). Consequently, the degree to which a firm learns and increases its stock of knowledge is a function of the extent of its participation in network activities (Levinthal and March 1994; Brown and Duguid 1991; Von Hippel 1988). A firm's learning is, however, both a function of its access to knowledge *and* its capability to utilize and build on that knowledge (Powell et al. 1996).

A firm's access to knowledge is a necessary condition for innovation to take place. In the process of innovation, a firm consumes information, transforms it, and produces a new product or process in a form that can be regarded as information bearing. Gibbons and Johnston (1974), for instance, define innovation as a set of problems a firm must solve. In order to solve these problems, innovative firms must learn where to find information and how to use that information. Then, they must have additional information from either external sources or from memory in order to develop possible solutions to their problems. Allen (1977) also notes that engineers must first have information in order to understand and formulate the problem confronting them. Freeman (1994), citing Stiglitz (1987) and Lundvall (1992), indicates that the picture that emerges from numerous studies of innovation in firms is one of continuous interactive learning that occurs in the context of formal and informal relationships between firms. In short, the sources of innovations do not reside exclusively inside firms; instead, they are commonly found in the interstices between firms, universities, and research laboratories (Powell 1990).

Much of the discussion of networks of firms as learning organizations relates to Japanese firms.[10] In fact, Nonaka and Takeuchi (1995) attribute much of the success of the Japanese firm

[10] See, for instance, studies by Freeman 1994; Goto 1982; Schonbeger 1982; Imai 1989; Imai and Baba 1989; Fransman 1990; Kodama 1990, 1991; Tanaka 1991; Friedman and Samuels 1992; Sako 1992; Dodgson and Sako

to its competitive advantage as a learning organization. Its learning capabilities emerge from an organization based on knowledge and special networks. In the following subsections, we focus on the contribution of Japanese-style networks to innovations.

Knowledge Networks

Some economists, notably Aoki (1986, 1988, 1990, 1991), regard the Japanese firm as having a specific form of organization differing in many important characteristics from the organization of American and European firms. In fact, the underlying presumption that an important source of Japan's industrial strength is in the organizational structure of the Japanese firm has generated a considerable economic and management literature in English dealing with various aspects of Japanese firms and with comparisons to their Western counterparts (Lamming 1987; Nishiguchi 1987; Krafcik and MacDuffie 1989; Krafcik 1990; Womack et al. 1990; Aoki 1990; Sayer and Walker 1992; Dore 1973, 1985, 1987).

Different firms' organizational forms offer different advantages as well as disadvantages for innovations. For instance, vertical integration potentially protects a firm's specialized research assets, permits it to capture the full gains associated with the resulting innovations, and provides an internal government scheme to manage organizational and technical uncertainties inherent in the innovation process (Nelson and Winter 1977). However, Tapon (1989) enumerates several failures inherent in a vertically integrated firm's internal innovation process, including difficulty in selecting the problems to investigate, opportunism which distorts communication of scientific knowledge that conflicts with careers goals, and difficulty in deciding how to compensate scientists commensurate with the value of their discoveries.

Instead of integrating *all* the functions within its organization (vertical integration), a firm can buy some of the functions from other firms using two other organizational forms: arm's length (open market) or networks (collaborative, long-term relationships). Networks, and in particular, Japanese-style networks, offer advantages in terms of innovations to high-tech firms

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1993; Bowonder and Miyake 1993.

competing in fast-changing markets (Aoki 1986). Womack et al. (1990: p. 142), for instance, describe problems associated with putting together about 25 parts for a new automobile seat being produced by arm's length suppliers: "When the parts were finally put together in the finished seat, it was not surprising that a piece would not fit or that two abutting materials will prove incompatible. For example, they might rattle or squeak in cold weather because of different expansion coefficients." These problems arise because an arm's length relationship restricts the transfer of technical knowledge between firms and seriously erodes their ability to coordinate activities in the innovation process (Tapon 1989; Teece 1981; Von Hippel 1988; Bolton et al. 1994). Another problem is that high levels of uncertainty regarding the technical characteristics of an evolving product or process may permit inroads for opportunistic behavior (self-seeking interest) by an arm's length exchange partner (Teece 1981).

On the contrary, network systems, or long-term collaborative arrangements between firms, facilitate the transfer of tacit (experiential) knowledge of the sort frequently involved in innovations. In particular, network systems offer advantages in the development and commercialization of new products to high-tech firms which experience high levels of uncertainty and short product cycles. There is, in fact, strong evidence that collaborative relationships (networks) with suppliers and customers gave Japanese innovative high-tech firms competitive advantages. Bolton et al. (1994), for instance, indicate that networks have accelerated the development of new technologies in the Japanese semiconductor equipment industry and have led to its extraordinarily rapid worldwide penetration. Moreover, using number of patents as an indicator of innovations, Grillinches (1989) notes that there has been a rapid growth in U.S. patents granted to Japanese electronics and motor vehicle firms. In fact, a recent study by NSF (1996) indicates that there was a dramatic increase in the number of U.S. patents granted to Japanese firms between 1983 and 1993, the latest year for which this information is available. According to this source, Japanese firms accounted for about 50% of all U.S. patents granted to foreign firms in 1993.

We use the contrast that Aoki (1990) establishes between the information structure of the American firm (denoted A firm) and the information structure of the Japanese firm (denoted J firm) as a pillar in our discussion of the correlation between characteristics of interfirm relationships and firms' innovation performance.[11] According to Aoki (1987, 1990), the main features of the coordination system of the J firm are (1) horizontal coordination among divisions within a firm or between different firms within a network and (2) sharing of ex post on-site information (learned results). Production decisions are coordinated among semiautonomous units that gradually become capable of responding to emerging events more quickly by better uses of knowledge (information learned through experience). This is one of the primary reasons why the Japanese tend to emphasize long-term relationships with other firms (and "lifetime" employment).[12]

Asanuma (1989), Aoki (1986, 1990), and Dyer (1996) maintain that customers and suppliers of a J firm, as a group, become *assets specific* to the internal network, in the sense that at least some of the technical and technological expertise of the suppliers and customers is *specific* to its relation with the J firm. The information processing and communication abilities of firms participating in a network are nurtured largely through learning in the context of a firm-specific coordination network. Such abilities cannot be acquired prior to membership in the network and their value cannot be truly realized in isolation from it. Repeated contacts in network organizations increase knowledge about the partner firms. It is therefore not necessary to have contracts that completely cover all contingencies; instead, contracts between firms are mostly implicit or open-ended, where the parties continuously renegotiate their agreements (Helper and Levine 1992). In this process, suppliers do not merely manufacture components

[11] However, because many American firms have emulated the Japanese way of communicating with suppliers and customers, it is difficult to talk of a pure American firm. In fact, some argue that the "Japanization" of U.S. manufacturing practices has slowed U.S. firms' loss of existing markets to foreign competitors (Helper 1993; Cusumano 1985). And, more recently, there is some indication of convergence between the two systems (Helper and Sako 1995).

[12] However, not all relations are collaborative. A firm usually establishes *both* collaborative and non-collaborative relationships with its suppliers. In the Japanese automobile industry, for instance, there is a wide range of technologically unsophisticated parts, such as boxes and cables, which are competitively sourced without extensive relationship building. It is, however, fair to assume that relationships conducive to innovations are mainly collaborative because of the dependence of innovations on knowledge.

according to the specifications provided by the manufacturers; in the process of supplying components, many other things are also exchanged: technical information, financial assistance, and personnel, for example (Itoh 1994). In short, a multitude of reciprocal relations exists where firms agree to repeated interaction and to the sharing of knowledge.

The early exchange of knowledge that characterizes J firm networks considerably shortens the lead time necessary for the development of *new products* (Imai et al. 1985; Aoki 1986). In particular, suppliers design and do the pilot fabrication of new parts parallel to corresponding activities at the J firm. The early involvement of the supplier in the development of new products or processes results in better coordination between the supplier and the J firm. Coordination is also facilitated because engineers from important supplier firms are housed in the development laboratory of the J firm as "guest engineers" or participate in the J firm's team on a permanent basis (Aoki 1984). However, early collaboration and exchange of information between firms in the development of new products only occurs once firms have developed expertise specific to the network, which requires firms to have worked together for a while (Aoki 1986).

On the contrary, in the traditional A firm, relationships between firms are performed in the context of an open market where *prices* are the sole means of coordination (Womack et al. 1990). The relationship between firms is based on bidding on the lowest price for components. This one-time nature of transactions inhibits the continuous interaction needed for the development of network-specific expertise and increases the likelihood that contracts are based on "complete" legal agreements. Aoki (1986) points out that arm's length relationships are advantageous to industries in which large scale planning across markets is beneficial or where non-repetitive coordination needs to be planned ex ante.

It is important to recognize that benefits associated with network organizations are not unique to the J firm, but to all firms (including A firms) in rapidly changing markets that organize their relationships with other firms based on the same principles: long-term tenure and a continuous exchange of information, allowing for the development of relation-specific (or network-specific) expertise. Based on this assumption and the previous discussion, we formulate the following hypothesis on the effects that relationships between firms have on firms' performance:

> *H1: Firms in highly volatile markets would have better innovative performance if they maintained network systems with suppliers and customers.*

Spatial Proximity

The spatial proximity of suppliers that usually characterizes the Japanese firm has been associated with the need to *deliver* components on a just-in-time basis. The emphasis has been on exchange of products, not exchange of information between Japanese network firms. Some argue, however, that spatial contiguity leads to information and knowledge flows (Enright 1995; Malecki 1996; Jacobs 1968; Chinitz 1961; Lucas 1988; Glaeser 1993; Rauch 1991). As Krugman (1991) points out, physical proximity may enhance knowledge flows by making casual (informal) communication less costly. In the case of the Japanese firm, Head et al. (1995) find support for the hypothesis that industry-level agglomeration benefits—including access to knowledge—have played an important role in the location decision of these firms in the United States.

Spatial agglomeration facilitates knowledge transfer not only between firms, but also between other organizations that are also important sources of "urban" knowledge—in particular, universities and high-tech services. Mowery (1995), for instance, notices that proximity to a network of other firms, universities, and support services remains critical to innovations. Jaffe (1989) and Feldman (1994) also found that product innovations exhibit a pronounced tendency to cluster geographically, and this geographic concentration at the state level is related to the level of university R&D and industry R&D expenditures in the state. In this view, innovation is a process facilitated by diverse types of expertise and knowledge available in cities (Kline and Rosenberg 1987).

Innovation is associated with the process through which knowledgeable people interact with one another and learn from this interaction. This interaction is enhanced by spatial proximity. One of the first researchers to make a connection between location and innovations was Bairoch (1989), who pointed out that towns favor both innovation and the dissemination of new technologies across wider areas. A large concentration of people generates more ideas, and because innovations depend on knowledge, innovations will be greater in places with a large pool of knowledgeable people. Thus, innovations are one of the benefits that result from the agglomeration of firms in space (Glaeser 1993; Rauch 1991; Jaffe et al. 1983; Audretsch and Feldman 1996; Audretsch and Stephan 1996).[13] The assumption behind this argument is that the concentration of skilled labor in one place speeds up the flow of information that leads to new products and processes. In particular, there is a belief that a large agglomeration of a *specialized* industry speeds up the movement of ideas by facilitating high levels of interfirm worker mobility and informal communication among engineers and scientists.

The idea of a positive relationship between proximity and firms' innovation performance presupposes the assumption that distance reduces the ability to receive knowledge. There may be geographical boundaries to knowledge flows, particularly tacit knowledge flows, among firms in an industry (Marshall 1920, Krugman 1991). In this respect, Audretsch and Feldman (1996) argue that although the cost of transmitting *information* may be invariant to distance, presumably the cost of transmitting *knowledge* rises with distance. That is, proximity and location do matter in the transmission of knowledge. In this view, although firms in network systems serve global markets and collaborate with distant customers, suppliers, and competitors (technology firms, in particular, are highly international), the most strategic relationships are often *local* because of the importance of timeliness and face-to-face communication for rapid product development. Neighboring firms can learn from each other much better than geographically isolated firms (Saxenian 1994). This discussion leads to the following hypothesis:

> *H2: Innovations depend on contacts between knowledgeable people, and these contacts are facilitated by spatial proximity. Thus, we will expect that the most innovative high-technology firms would tend to have strong local networks.*

[13] Other benefits include availability of specialized labor and services, savings in transportation costs, and economies of scale (Krugman 1994).

While acknowledging the important role that knowledge spillovers play in the localization of some industries, Krugman (1991) and Head et al. (1995) are wary about assuming that this is the *dominant* reason—even in high-technology industries where most innovative activity takes place. Krugman (1991) cautions that there is no reason to assume that the motives for high-technology firms to agglomerate are different from the motives for non-high-technology firms. According to Marshall (1920), there are two other compelling reasons, besides the flow of ideas, for firms in the same industry to agglomerate: a pooled market of workers with specialized skills and the availability of specialized inputs and services. A localized industry will attract *specialized workers* for two reasons. First, as argued by David and Rosenbloom (1990), the spatial concentration of industry is advantageous to laid-off workers who will be able to find jobs with other firms. Hence, an increased number of firms reduces the likelihood that a worker will suffer a long bout of unemployment. Second, workers in a determined location will be more inclined to invest in industry-specific human capital if they feel confident of their ability to appropriate the benefits (Rotember and Saloner 1990). By mitigating the hold-up problem, agglomeration generates the development of more industry-specific skills. A large industry will also create a spatial demand of considerable size to allow complementary business services to exhaust economies of scale. Furthermore, the presence of *specialized services* in the city will allow the large industry to buy some of the functions from other firms in the city. In short, spatial proximity to other businesses allows a firm to enjoy the benefits of higher levels of specialization.

There are two hypotheses about the relationship between spatial agglomeration and innovations. According to Krugman (1991) and Head et al. (1995), the exchange of ideas (and its positive effect on innovations) is not the main reason why high-technology firms agglomerate; rather, economies of specialization associated with specialized labor and specialized services are the main reason. In this sense, the reasons why high-technology firms locate near each other are not very dissimilar from the ones for non-high-technology firms—essentially, the availability of specialized labor, inputs, and services. Thus, the clustering of the high-technology industry is the result of benefits associated with firms' specialization, not those associated with local knowledge. Most knowledge relevant to the development and commercialization of new products and processes would come from linkages with organizations outside the region, not necessarily from linkages in the local economy. Based on Krugman (1991) and Head et al. (1995), we formulate the following hypothesis:

> *H3: Innovations depend mainly on non-local knowledge externalities from linkages with economic organizations outside the region. Thus, we would expect that innovative firms tend to have strong non-local linkages.*

Before we analyze employment trends in high-technology regions and estimate our logit models to test the hypotheses resulting from the literature review, we need to choose criteria that allow us to classify industries as high tech. Thus, the following section summarizes the discussion on various criteria to classify industries as high or non-high-tech.

Section 2
Definition of High-Technology Manufacturing and Services

Most of the issues in deciding whether to classify an industry as high tech revolve around finding a proxy for technology. Once this proxy is found, defining whether an industry is high tech is an easy task. This usually implies dividing industries into two groups: industries for which the selected proxy for technology shows a value above the average for all industries (the high-tech group) and those showing a value below this average (the non-high-tech group). The difficulty arises because "technology" is a broad concept that can be associated with, among other things, products, processes, services, know-how, R&D, innovations, skilled labor, and machinery and equipment. Identifying high-tech industries is difficult even when one assumes that *several* of these characteristics define a high-technology industry—that is, it might be an industry that produces high-tech products, invests highly in R&D, is highly innovative, and uses a lot of know-how and high-tech processes and equipment. Yet, what about an industry that produces a "non-high-tech" product but uses high-tech equipment, such as the production of chocolate chip cookies (an example mentioned by Broz et al. 1993)? Is it a non-high-tech firm? Moreover, although most of these measures are positively correlated, levels of correlation vary between them. For instance, Feldman (1994) reports correlations with innovations (measured as the number of new products from the Small Business Administration Data Base) of 0.85 with R&D, but of only 0.70 with high-tech employment (as defined by Markusen et al. 1986).

There are also problems in the definition associated with changes over time—an industry may be high tech at one time, but not at a later date. Malecki (1991), for instance, suggests that if high-tech firms use the latest technology, the industries in which they are involved will be younger. The semiconductor industry, which did not exist 30 years ago, is a good example of this. Another time consideration is the degree of product/process obsolescence (OECD Study 1986 cited by Butler 1992). One would expect that high-tech firms work in rapidly changing areas, and therefore experience a higher degree of product and/or process change than other industries. The major disadvantage to this definition is that it has not yet been made operational. Obsolescence may be hard to measure, as processes sometimes remain in existence several years after they have become outdated.

Other proxies for high technology come from the assumption that high-technology industries are those that create economic progress. If economic progress is understood in the "growth pole" context, high-technology industries should have extensive links to other industries. Imai (1988), for instance, defines high-technology industries as being "system oriented," which implies that they create products used in many other industries. Moreover, Malecki (1991) maintains that if high-tech industries are propulsive sectors (with strong backward and forward linkages), then they should grow faster than other industries. There is not, however, an objective reason to anticipate that high-tech industries should have strong backward and forward linkages.

Most empirical studies that classify industries as high tech use as a criterion either a proxy of technology intensity or a proxy for the contribution of firms to economic development, in particular, job creation (Office of Technology Assessment 1984).

Proxies to Measure High-Technology Manufacturing

Job generation: *percentage increase in industry employment, compared to average of all industries* (Technical Market Associates 1979 cited in Markusen et al. 1986). The hypothesis is that high-technology industries generate more jobs than other industries. This neglects high-technology industries that are not yet commercially viable and have not led to rapid employment growth. It also misclassifies high-technology industries in which employment growth fluctuates, such as defense industries. Finally, it fails to acknowledge other sources of job growth, such as relative price changes or import substitution. This definition then includes as high-tech industries those which experience rapid employment growth, whether or not they actually are high tech.

Research and development: *R&D as a percentage of value-added or as a percentage of sales* (Davis 1982, Scherer 1982). The hypothesis is that high-tech industries have higher than average R&D expenditures, which implies that high-tech industries are at the early stages of the product cycle. Once a product matures (so that R&D is no longer crucial), the industry is no longer considered high tech. A disadvantage of using R&D expenditure to measure the level of technology of an industry is that one may misclassify mature industries that could reasonably be called high tech. One may also misclassify industries or products which have high value-added or large sales, even if a relatively large amount is spent on R&D. Finally, many measures of R&D aggregate quite different mixes of basic and applied research with the more routine advertising and marketing research, the latter of which has virtually nothing to do with technology.

Researcher perception: *views or opinions of "experts" are used to classify industries as high tech.* This definition allows the researcher leeway to base classification on several factors at once without limiting the weight put on any one factor. The weaknesses of this method of classifying industries are obvious. First, no objective criteria are used to classify industries, so links between causes and effects are impossible to measure. Second, classification is based on opinions, which differ from individual to individual and country to country. An example of this kind of definition is the one used by the American Electronic Association (1997).

Capital/skilled-labor intensity: *measure of the physical capital-to-skilled-labor ratio of an industry.* The hypothesis is that high-technology industries are more skilled-labor intensive than other industries; therefore, they will show *low* ratios of capital to labor. Because high-tech industries usually have higher levels of innovation, they are more likely to employ highly skilled workers in production in place of large amounts of capital. The major disadvantage of this definition is that some industries with relatively high capital investments may not be classified as high tech. Such would be the case of the semiconductor industry, where specialized equipment for research leads to a very *high* capital/skilled labor ratio.

Information intensity: *importance of information, as a product or input, to the industry.* The hypothesis is that high-technology industries are much more information intensive than others. However, information intensity would be hard to measure.

Defense related: *federal government or defense contractor as major customer.* Many high-technology industries arose from defense-related spending, so lots of defense-related work implies that the industry is high tech. However, the Department of Defense also buys a lot of non-high-tech products. Moreover, not all high-tech firms have defense contracts.

Employment statistics: *percentage of "human capital" jobs in an industry.* High human capital jobs include engineers, technicians, scientists, mathematicians, or a combination thereof. The hypothesis is that high-technology industries employ more highly-skilled workers than other industries. Markusen, Hall, and Glasmeier (1986) found that the national average of engineers, engineering technicians, computer scientists, life scientists, and mathematicians for all industries was 5.82 percent.[14] They defined industries as high tech if the industry average exceeds 5.82 percent. Based on this classification scheme, 29 sectors (3-digit SIC) were classified as high tech. Within these sectors, 100 4-digit industries were listed as high tech (see Table 1 in Appendix A). The main drawback of this definition is that while some firms may be high tech, it may not be accurate to label the entire industry high tech. More specifically, definitions of high-technology industries based on the SIC system do not account for technological differences between firms in the same industry or between establishments (or plants) within the same firm. We avoid this problem by asking *each establishment* in our sample what percentage of its labor force is represented by engineers and scientists (to our knowledge, this is the first time that this exercise has been done). Based on this information, we reclassified each establishment in our sample into two groups of firms. Those in which at least 6 percent of their total employees are engineers and scientists we classify as *high-tech firms,* and those with a proportion of engineers and scientists less than 6 percent we classify as *non-high-tech firms.*

We use a definition of high technology that is based on the percentage of human capital in a manufacturing establishment because it offers several competitive advantages over other definitions. In particular, human skills highly correlate with other indicators of "technological" performance, such as R&D (Berman et al. 1994), the stock of capital, and information intensity. Job classifications are available from objective (rather than self-reported) sources and carry across industries (manufacturing and service). Human capital is associated with positive effects on

[14] Based on the 1980 Occupational Employment Statistics (OES) survey-based matrix.

economic development at the national (Romer 1986; Suarez-Villa 1990) and regional (Glaeser 1994; Lucas 1988; Rauch 1991; Krugman 1991) levels. More important, communication between individuals with large endowments of human capital is the main input in the production of knowledge and therefore innovations, the focus of this study.

High-Technology Services

The term 'producer services' generally includes the following non-production activities: finance, insurance, and real estate (FIRE); legal services; transportation and communication; accounting; advertising and marketing; research and development; data processing; and worker and management training. Hansen (1994) notes that the SIC categorization scheme insufficiently distinguishes the different markets for services and classification of business functions; however, it is still the best available classification scheme for consideration of producer services. He uses two sectors, Business Services (SIC 73) and Engineering, Accounting, Research, Management and Related Services (SIC 87), as best approximation for producer services. Beyers and Lindahl (1996), who focus on processes externalized by large corporations due to specialization of function, include a different subgroup of SIC codes in their definition of producer services (SIC 61-64, 736, 737, 7389, 81, and 871-874).

This report is concerned with employment in producer services which are considered high tech. Vinson and Harrington (1979, cited by Markusen et al. 1991) list the following high-tech industry service-related SIC codes (changed to reflect 1987 categorization codes), as determined by product sophistication: Computer Programming, Data Processing, and Other Computer Related Services (SIC 737, except 7378 Computer Maintenance and Repair); Engineering, Architectural, and Surveying Services (SIC 871); Research, Development, and Testing Services (SIC 873); Management and Public Relations Services (SIC 874); and Accounting, Auditing, and Bookkeeping Services (SIC 8721). This is the classification we use in this report.

Section 3
Employment Changes in U.S. High-Technology Regions

The focus of this section is a comparative analysis of changes in employment in what we call the "traditional" high-technology regions—Silicon Valley,[15] Research Triangle Park (RTP),[16] Route 128,[17] and Southern California[18]—and in the five largest metropolitan areas in Texas—Houston, Dallas, Fort Worth, San Antonio, and Austin. This section is divided into two parts. In the first part, we analyze employment changes in the four traditional high-technology regions, highlighting some important historical features of the development of these regions. In the second part, we analyze the dynamics of relatively "new" high-technology regions in Texas.

The Traditional High-Tech Regions

Consistent with the focus in this section on changes in high-tech employment, this subsection presents a very brief history of the high-technology industry in each traditional region. We also keep this section short because these regions have been extensively analyzed in previous studies. A detailed account of the high-technology industry in Silicon Valley is found in Saxenian (1994), Route 128 in Saxenian (1994), Southern California in Scott (1993), and Research Triangle Park in Luger and Goldstein (1991). Premus (1982) and Campbell (1986) have done comparative studies of Silicon Valley, Route 128, and Research Triangle.

In all of the traditional high-technology areas, proximity to a major university proved crucial for development of a high-tech concentration because proximity generated relationships which led to the formation of firms that commercialized academic research. Silicon Valley and Route 128 developed through a combination of spin-offs from university research—Stanford

[15] Silicon Valley includes five California counties: Alameda, San Francisco, San Mateo, Santa Cruz, and Santa Clara.

[16] The Research Triangle Park includes six North Carolina counties: Chatham, Durham, Franklin, Johnston, Orange, and Wake.

[17] Route 128 includes four Massachusetts counties: Middlesex, Suffolk, Norfolk, and Essex.

[18] The high technology complex of Southern California includes seven counties: Santa Barbara, Los Angeles, Ventura, Orange, Riverside, San Diego, and San Bernardino.

University for Silicon Valley and Massachusetts Institute of Technology for Route 128. A second factor in the development of these concentrations of high-technology firms was defense-related spending. Route 128, Southern California, and Silicon Valley have received significant defense-related contracts. This is less true for RTP; however, government support was crucial in the formation of the park and remains key.

Silicon Valley's history begins in 1909, when Stanford's president funded research on the vacuum tube. In the late 1930s, David Hewlett and William Packard formed a company to commercialize research in audio oscillators that they had done as students at Stanford. By the 1950s, several other research projects had led to the creation of businesses, and Silicon Valley had begun (Saxenian 1994).

Route 128 began in the 1950s, with the founding of Digital Equipment Corp. (DEC) by Ken Olsen, Stan Olsen, and Harlan Anderson (Hansen and Dabney 1994). This company was a spin-off from Massachusetts Institute of Technology, but led the region on a different trajectory than the one Silicon Valley took. Development of Route 128, most of which occurred in the 1970s and 1980s, was mainly through federal government funding of large companies. Major companies located in the area include DEC, Lotus Development, and Wang (Saxenian 1994).

Research Triangle Park, founded in 1959, was one of the first "planned" high-tech concentrations.[19] It is located in North Carolina, in the triangle between Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill. Occupancy in RTP did not really take off until IBM located in the park in 1965 (Luger and Goldstein 1991). American and foreign firms in RTP work in several areas of high technology, including biotechnology, electronics, computers, and telecommunications. The only requirement for a firm wishing to locate within the park is that they be engaged in "research, development, and scientifically oriented production." Thus, while RTP is not specifically designed to attract high-

[19] According to Luger and Goldstein, RTP's strategy has been "to place the highest priority on attracting the branch plants of major corporations rather than new, small, start-up, technology-oriented businesses" (p. 78).

technology firms, the requirement of scientific R&D has led to a concentration of high-tech firms in the area (Luger and Goldstein 1991).

According to Scott (1993), the birth of the aircraft industry in Southern California occurred in the 1920s and 1930s. Among the earliest aircraft firms to settle in the region were the Douglas Aircraft Company and the Lockheed Aircraft Company. The aerospace-electronics industrial complex of Southern California became more deeply entrenched in the region in the 1950s, and it came typically to consist of large establishments surrounded by dense networks of smaller establishments providing various kinds of specialized material inputs and services. Four major industrial sectors would seem to embody most of the high-technology industrial activity in the region: Ordnance (i.e., missiles) and Accessories (SIC 19), Communications Equipment (SIC 366), Electronic Components (SIC 367), and Aircraft and Parts (SIC 372) (Scott 1993).

To analyze employment changes, both in high-tech manufacturing and high-tech services in these regions, we used data from *County Business Patterns* for 1989 and 1993 (the latest years for which these data are available)[20] (see Table 2).

[20] We used 1993 data since these were the latest data available at the time of this research. Data for 1994 are now available, though we do not expect that using 1994 data would significantly change our results. More current employment data are published by the Bureau of Labor Statistics, but these data are available only at the state level.

Table 2. Employment data by high-technology regions for 1989 and 1993.

Region	High-technology services		High-technology manufacturing		Total high technology		Total manufacturing		Total employment	
	1989	*1993*	*1989*	*1993*	*1989*	*1993*	*1989*	*1993*	*1989*	*1993*
San Antonio	10,670	16,632	7,192	6,898	17,862	23,530	45,855	47,533	576,368	643,858
Austin	14,796	21,152	27,024	32,518	41,820	53,670	46,125	54,567	391,069	468,689
Fort Worth	12,456	18,678	54,317	44,349	66,773	63,027	112,390	100,791	542,206	603,674
Dallas	60,780	78,249	68,931	67,205	129,711	145,454	235,589	225,560	1,442,786	1,576,709
Houston	66,062	86,371	58,472	63,460	124,534	149,831	170,853	188,310	1,551,653	1,722,567
Texas total	**164,764**	**221,082**	**215,936**	**214,430**	**380,700**	**435,512**	**610,812**	**616,761**	**4,504,082**	**5,015,497**
Research Triangle	17,864	23,921	23,276	40,560	41,140	64,481	78,530	76,496	476,778	530,471
Route 128	90,479	114,010	115,035	85,052	205,514	199,062	314,418	241,997	1,528,419	1,391,614
Silicon Valley	127,950	139,172	203,232	151,823	331,182	290,995	549,085	418,752	2,559,100	2,514,414
Southern CA	285,949	297,259	445,498	353,325	731,447	650,584	1,449,945	1,166,344	7,971,581	7,672,068

These data were extracted from County Business Patterns (CBP) CD ROMs for 1989-90 and 1992-93. Total Employment was calculated as the sum of total employment from CPB (which excludes the government sector) plus government totals from the Bureau of Economic Analysis (BEA) CD ROM. Data were collected by county and aggregated for regional totals. See Appendix B for explanation of how total employment was calculated.

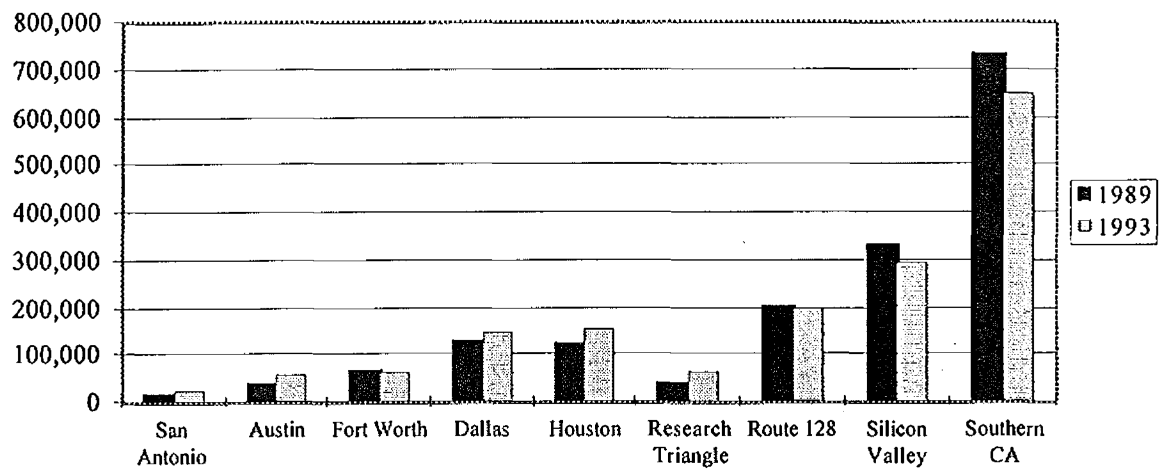
High-tech *manufacturing* industries were determined according to the definition of Markusen, Hall, and Glasmeier (1986). The definition is based on percentage of engineers, engineering technicians, computer scientists, life scientists, and mathematicians in the industry labor force, and comprises 100 four-digit SIC codes (see Appendix A). High-tech *service* industries were determined by product sophistication according to Vinsen and Harrington (1979) and include the following SIC codes (changed to reflect 1987 categorization codes): 737 Computer Programming, Data Processing, and Other Computer Related Services, 871 Engineering, Architectural, and Surveying Services, 873 Research, Development, and Testing Services, and 874 Management and Public Relations Services. This definition is extended to include all four-digit SIC codes included within this group (except 7378 Computer Maintenance and Repair) and also includes 8721 Accounting, Auditing, and Bookkeeping Services.

The following counties are included in each region:

San Antonio—Bexar, Comal, Guadalupe, Wilson.
Austin—Bastrop, Caldwell, Hays, Travis, Williamson.
Fort Worth—Hood, Johnson, Parker, Tarrant.
Dallas—Collin, Dallas, Denton, Ellis, Henderson, Hunt, Kaufman, Rockwall.
Houston—Chambers, Fort Bend, Harris, Liberty, Montgomery, Waller.
Research Triangle—Chatham, Durham, Franklin, Johnston, Orange, Wake.
Route 128—Essex, Middlesex, Norfolk.
Southern California—Santa Barbara, Los Angles, Ventura, Orange, Riverside, San Diego, San Bernardino.
Silicon Valley—Alameda, San Francisco, San Mateo, Santa Cruz, Santa Clara (includes San José).

Figure 1 shows that Southern California is by far the largest among traditional high-technology regions in the United States, employing 650,584 workers in high-tech manufacturing and services in 1993. This high-tech region had twice the Silicon Valley high-tech employment (including both manufacturing and services), four times that of Route 128, and eight times that of RTP in 1993.

Figure 1. High-tech employment* by region for 1989 and 1993.

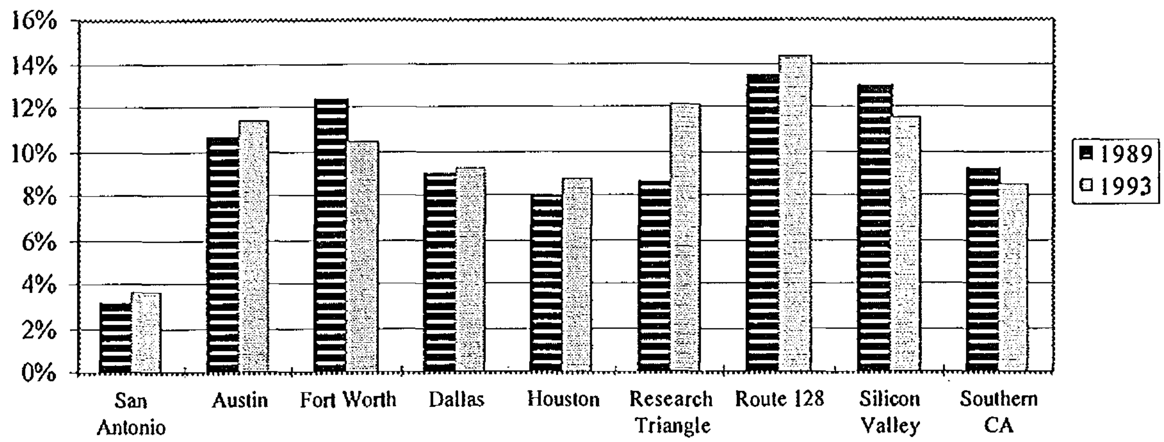


* The sum of high-tech services and manufacturing. Source: Table 2.

In spite of the significance usually associated with the high-technology industry in the traditional high-tech regions, employment data indicate that the dependency of these regions on high tech is relatively low. Figure 2 shows that in 1993, high-tech employment (including both manufacturing and services) was only 14 percent of total employment in Route 128, 12 percent in RTP, 11 percent in Silicon Valley, and 8 percent in Southern California. Even when only participation in manufacturing employment is considered, all traditional regions show a significant level of manufacturing diversification outside the high-technology sector.

Thus, as Figure 3 indicates, with the exception of RTP, in which high-tech manufacturing employment jumped from 29 to 53 percent between 1989 and 1993, high technology represented less than 35 percent of manufacturing employment in the other three traditional high-tech regions in 1993. It is important to note that between 1989 and 1993, all the traditional regions lost high-tech employment. Southern California lost 80,863 high-tech jobs, followed by Silicon Valley with 40,187 and Route 128 with 6,452. Only the RTP region gained high-tech jobs (23,341).

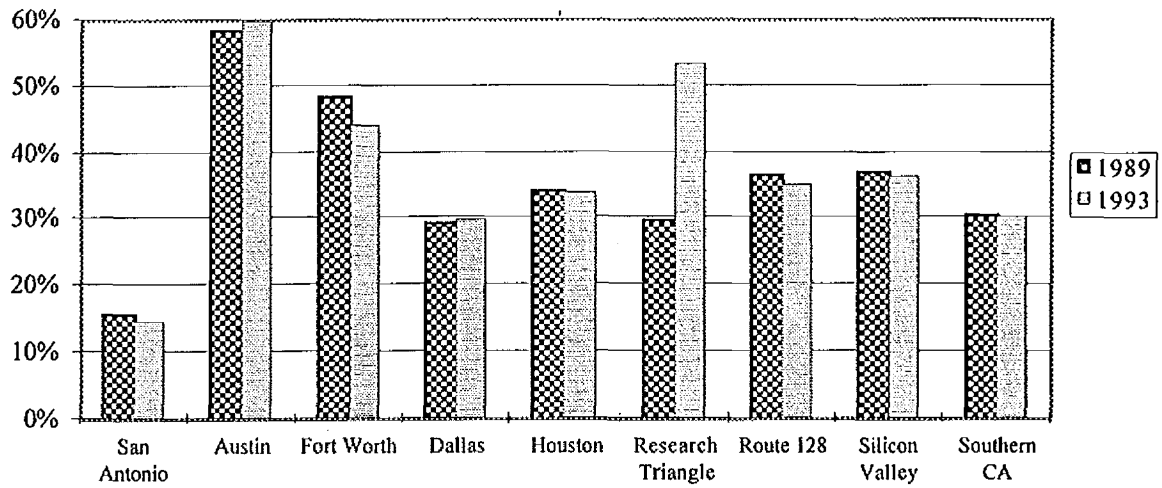
Figure 2. High-tech employment* as percentage of total employment by region for 1989 and 1993.



* The sum of high-tech services and manufacturing. Source: Table 2.

Data from Table 3 in Appendix C show that specialization by high-tech manufacturing sectors varies by region. In 1993, Route 128 was highly diversified with several high-tech sectors contributing to the performance of the high-technology industry in this area, including electronic components, semiconductors, surgical and medical instruments, aircraft engines and engine parts, and telephone and telegraph equipment. Silicon Valley was somewhat less diversified, producing mainly semiconductors, computers, missiles and space vehicles, and electronic components. Conversely, Southern California was heavily specialized in the production of aircraft, aircraft parts, and missiles and space vehicles, while RTP was mainly specialized in the production of computers. Differences in the magnitude of employment in the *top* high-tech manufacturing sectors in each region is quite dramatic. For instance, in 1993, the top high-tech manufacturing sector in Southern California, aircraft and aircraft parts, employed 88,000, while the top high-tech manufacturing sector in Route 128, electronic components, employed only 9,000.

Figure 3. High-tech manufacturing as percentage of total manufacturing employment for 1989 and 1993.



Source: Table 2.

In terms of high-tech services, data from Table 4 in Appendix C indicate that Route 128 specialized in Engineering Services (SIC 8711), Prepackaged Software (SIC 7372), and Computer Programming Services (SIC 7371); Southern California specialized mainly in Accounting, Auditing, and Bookkeeping Services (SIC 8721) and in Engineering Services; Silicon Valley in Prepackaged Software and Engineering Services; and RTP in Engineering Services, Commercial Physical and Biological Research (SIC 8731), and computer-related services (SIC 7373 and 7371). Differences in the magnitude of employment in the *top* high-tech service sectors in each region is also quite dramatic. For instance, in 1993, in Southern California, the two top high-technology services, Accounting, Auditing, and Bookkeeping Services and Engineering Services, employed 64,000 and 51,000, respectively, while in RTP, the top high-tech service sector, Engineering Services, employed only 3,000.

High-Technology Regions in Texas

Unlike the situation for the traditional high-tech regions, there is no single source for the history of the high-technology industry in Texas; only short and discontinuous highlights for each metropolitan area are available.[21] This is probably because high-tech specialization in the five largest metropolitan areas of Texas (Houston, Dallas, Fort Worth, San Antonio, and Austin) is so diverse. A history of the chemical industry in Houston would shed little light on the concentration of aircraft manufacturers in Fort Worth or semiconductor firms in Austin and Dallas. Statements that apply to the aircraft industry in Fort Worth will not apply equally to the petrochemical industry in Houston. Cuts in defense spending have impacted Fort Worth and Dallas much more than Austin.

Austin: The Silicon Hill

In the late 1950s, four graduate students of the University of Texas School of Engineering founded Tracor Inc., probably the first large high-tech firm in Austin. IBM arrived in 1967, focusing its worldwide development of office systems in Austin. Motorola, whose memory technologies and microprocessor divisions are headquartered in Austin, located its first facility here in 1974. Applied Materials, the world's largest supplier of equipment to the semiconductor industry, began its first Austin facility in 1990. These companies have been joined by Advanced Micro Devices (AMD), Texas Instruments, Data General, Tandem Computers, Rolm, and others.

Austin's concentration of semiconductor manufacturing has increased significantly. In 1995, both Motorola and AMD completed $1 billion wafer fabrication facilities, which are among the most capital intensive of facilities in any industry. Samsung Electronics, the industry's largest memory manufacturer, is also building a $1.3 billion memory manufacturing facility in Austin. Two research consortia dedicated to U.S. technological leadership in computers and microelectronics, the Microelectronics and Computer Technology Corporation (MCC) and

[21] See, for instance, the *Houston Business Journal* for Houston, the *Dallas Business Journal* for Dallas and Fort Worth, the *San Antonio Business Journal* for San Antonio, and the *Austin Business Journal* for Austin.

Sematech, are headquartered in Austin. Austin has also become a national center for software development with more than 500 software companies already present.

The Austin Metropolitan Statistical Area (MSA) consists of Bastrop, Caldwell, Hays, Travis, and Williamson counties. As data from Table 2 indicate, total high-tech employment in both manufacturing and services in the Austin metro area was 53,670 in 1993, with 32,518 in manufacturing and 21,152 in services. Total high-tech employment accounts for only 11.4 percent of total employment in the Austin MSA, indicating a high level of economic diversification (see Figure 1). However, high-technology employment accounts for almost 60 percent of *manufacturing* employment in this area, a greater concentration of high-tech manufacturing employment than in any of the other major high-tech areas considered in this report (see Figure 3). The Austin MSA gained 11,850 high-tech jobs between 1989 and 1993 (see Table 2). Data from Table 3 indicate that the top two high-technology manufacturing sectors (and the most dynamic ones) in the Austin MSA are Electronic Components (SIC 3679) and Semiconductors (SIC 3674), with employment gains of 4,000 and nearly 2,000, respectively, between 1989 and 1993.

High-tech services gained 6,356 new jobs between 1989 and 1993. Engineering Services (SIC 8711) is the top high-tech service industry in the Austin MSA; however, the largest employment gains between 1989 and 1993 occurred in Management Services (SIC 8741) and Computer Integrated System Design Services (SIC 7373) (see Table 4).

With the exception of one firm, all the firms we interviewed in Austin produce in at least one of these two sectors: Electronic Components and Semiconductors. When asked the reasons for being in Austin, the most important reason mentioned in our interviews was the quality of life in Austin. Quality of life plays a key role in several forms: the nice weather and a large percentage of highly educated people (more books are purchased per capita in this city than almost any other city in the United States) make it easier for firms to attract engineers from outside the city. The location of other high-tech firms in Austin also makes workers more interested in living in this city. It is easy to get customers to visit Austin all year round (this benefit becomes more important in winter). Other reasons given were: (a) the founder was here either because he got his Ph.D. at the University of Texas or the firm is a spin-off from a large high-tech firm already located in the city, (b) the major customers are located here, or (c) the city is centrally located for distribution to customers located outside the city.

Dallas: Defense Cuts and Diversification

The Dallas MSA consists of Collin, Dallas, Denton, Ellis, Henderson, Hunt, Kaufman, and Rockwall counties. As data in Table 2 indicate, total high-tech employment in the Dallas metro area was 145,454 in 1993, with 67,205 in manufacturing and 78,249 in services. The area is highly diversified, with only 9.2 percent of total employment in the high-tech manufacturing and services sectors in 1993 (see Figure 2). Moreover, high-tech employment was only 30 percent of manufacturing employment in the Dallas MSA in 1993 (see Figure 3). Dallas' high-technology industry centers around semiconductors, telecommunications, and defense-related sectors such as aircraft parts production.

The Dallas metropolitan area gained 15,743 high-tech jobs between 1989 and 1993. However, most of the gains were in the service sector; high-tech manufacturing lost 1,726 jobs. Data from Table 4 in Appendix C indicate that the top high-tech manufacturing sectors are Aircraft Parts (SIC 3728) and Semiconductors (SIC 3674). Also, a large telecommunications sector specialized in the manufacture of Telephones and Telegraph Equipment (SIC 3661) is located in Richardson, a Dallas suburb. In fact, while the first two sectors experienced job losses, the Telephones and Telegraph Equipment sector gained 4,185 new jobs between 1989 and 1993. This shift is the result of the metropolitan area beginning to reduce its dependence on the defense industry and to concentrate on other high-technology industry sectors that are less dependent on defense contracts, such as semiconductors and telecommunications. The defense industry in Texas is the second largest in the nation, with many of the state's largest defense companies operating in the Dallas/Fort Worth area. General Dynamics, Bell Helicopter/Textron, Vought Aircraft, and Texas Instruments accounted for over 50 percent of defense contracts in 1991

(Greater Dallas Chamber 1996). Reductions in defense spending have hit the Dallas area hard: aircraft parts production lost 9,710 jobs between 1989 and 1993.

Contrary to the scenario in the manufacturing sector, high-tech services in the Dallas metropolitan area gained 17,469 new jobs between 1989 and 1993 (see Table 2). Computer Processing and Data Preparation Services (SIC 7374) and Management Services (SIC 8741) are by far the two largest high-tech services in the Dallas MSA. Computer Processing and Data Preparation Services gained 1,327 jobs between 1989 and 1993, while Management Services (SIC 8741) and Management Consulting Services (SIC 8742) gained 4,768 and 2,069 jobs, respectively, during the same period (see Table 4).

Of the four Dallas firms we interviewed, two are in the telecommunications industry, one is involved in semiconductor production, and one is involved in both industries. Company A is located in Richardson mainly because of the airport—it is easy to get from DFW to any place in the world. Additionally, Richardson is a nice place to live—the schools are good and housing is relatively inexpensive. This company can find experienced labor here; in fact, there is quite a bit of labor market fluidity, as engineers often move from this company to competitor firms also located in Richardson and vice versa. Company B is located in Dallas mostly due to historical accident (it was founded here in the 1930s to supply equipment to oil drilling companies). Company B also mentioned as an advantage the airport, which makes it easy for this company to access global markets. Company C is also located in Dallas because of historical accident; it started in Dallas 50 years ago; additionally, other telecommunications companies provide a source of engineers, which this company likes to hire from its local competitors. Company D was a spin-off of Texas Instruments. Dallas is a good location for the firm because there are other high-tech firms in the area, which are a source of qualified technicians.

Fort Worth: Aircraft Production

The Fort Worth MSA consists of Hood, Johnson, Parker and Tarrant counties. Total high-tech employment accounted for 63,027 in the Fort Worth metropolitan area in 1993, with

44,349 employed in manufacturing and 18,678 in services. High-tech employment accounted for only 10.4 percent of total employment in this MSA in 1993. However, high-tech employment was 48 percent of total manufacturing employment in 1989 and 44 percent in 1993 (see Figure 2). The top manufacturing high-tech sector by far is Aircraft Production (SIC 3721) (see Figure 3), due to the Lockheed-Martin plant located in Fort Worth which employs more than 12,000 workers. In 1989, employment in the aircraft industry was 8.5 times larger than employment in the next four largest high-tech manufacturing sectors combined. The Fort Worth area was also strongly hit by cuts in defense spending, resulting in the net loss of 9,968 jobs in manufacturing. The impact of defense cuts is seen more clearly when we analyze employment changes by sectors. Aircraft Production lost 20,000 between 1989 and 1993, but Production of Aircraft Parts gained 6,000 jobs in the in the same period (see Table 4).

High-tech services gained 6,222 new jobs between 1989 and 1993 (see Table 2). The top high-tech services in the Fort Worth MSA are Accounting, Auditing, and Bookkeeping Services (SIC 8721) and Engineering Services (SIC 8711). Between 1989 and 1993, 886 jobs were lost in the first sector, while only 136 jobs were gained in the second sector (see Table 4). However, other service sectors such as Management Consulting Services (SIC 8741) and Information Retrieval Services (SIC 7375) showed gains in employment.

Both Fort Worth firms we talked to were in the aircraft industry. Company A is located in Fort Worth mainly due to historical accident. The government built a factory in Fort Worth to make planes during WW II and sold it to the company after the war. In fact, the government still owns the building in which this company is located. Company B is located in Fort Worth because it has many good flying days every year.

Houston: The Oil and Gas Technology Capital of the World

The Houston MSA consists of Chambers, Fort Bend, Harris, Liberty, Montgomery, and Waller counties. Total high-tech employment in this metro area accounted for 149,831 in 1993 with 63,460 in manufacturing and 86,371 in services (see Table 2). Houston has always been home to a large variety of oil field equipment manufacturing and service firms. The concentration, however, has increased markedly in the past decade because these firms have retreated and restructured, closing offices in other cities and consolidating operations in Houston. Spurring on this trend has been nearly a decade of low oil and gas prices. Few people can forget the heady days of the 1970s and early 1980s, when OPEC controlled the world oil market and prices climbed from $3.89 barrel in 1973 to as high as $40 a barrel in 1981. Then came the collapse of prices in early 1986, when Saudi Arabia flooded the world with crude oil in order to regain market share. Some oil sold for under $10 a barrel. In the ensuing years, oil prices have recovered only partially, ranging between an annual average of $14 to $20 per barrel. Shocked by reduced operating income, oil companies reacted by cutting exploration and drilling activities, resulting in the retrenching of the industry. The companies that survived were leaner and most opted to concentrate their resources in Houston (Greater Houston Partnership 1995).

High technology represented only 8.6 percent of total employment (see Figure 2) and 34 percent of manufacturing employment in Houston in 1993 (see Figure 3). High-tech manufacturing in the Houston metropolitan area gained 4,988 new jobs between 1989 and 1993 (see Table 2). Data from Table 3 indicate that the top two high-tech manufacturing sectors in the Houston area are Oil and Gas Field Machinery (SIC 3533) and Industrial Organic Chemicals (SIC 2869). While the first sector lost 2,590 jobs between 1989 and 1993, the second sector gained 2,017 new jobs during the same period.

High-tech services gained 20,309 new jobs between 1989 and 1993 (see Table 2). The top two employers in the high-tech service industry were Engineering Services (SIC 8711) and Accounting, Auditing, and Bookkeeping Services (SIC 8721), which showed job gains of 11,099 and 2,094, respectively, between 1989 and 1993. Computer Programming Services (SIC 7371), the fourth largest employer in the high-tech service sector, showed the second largest gain in new jobs, 3,902, in the same period (see Table 4).

Of the five companies we interviewed in Houston, two produce Industrial Organic Chemicals (SIC 2869), one makes Oil and Gas Field Machinery (SIC 3533), and two produce

Plastics Materials (SIC 2821). Company A, the second largest producer of oil drilling rigs in the world, is located in Houston because that is where most of the oil industry is concentrated. Company B is the largest manufacturer of polypropylene in the world, and it is located in Houston because that is where the suppliers of its most important raw material, monomers (a byproduct of oil refining), are located. Since this raw material is shipped between Company B and its suppliers via pipeline, proximity is important. Company C is located in Houston mainly because raw materials for the production of pesticides are plentiful and because transportation of inputs and final products is easy. Houston is also a good location for the chemical industry because of its plentiful water, which is key for chemical plants. Company D makes intermediate chemical products, in particular, polyurethane (which is foamed and used in carpets and fiber applications) and polyvinyl alcohol. Chemical and especially petrochemical manufacturers, Company D's most important suppliers, pipeline its main components in. Company E receives chemicals from its customers (most of which are chemical firms) and separates them, usually through distillation.

San Antonio: An Emerging High-Tech Center

The San Antonio MSA consists of Bexar, Comal, Guadalupe, and Wilson counties. High-tech employment accounted for 23,530 jobs in 1993, with 6,898 in manufacturing and 16,632 in services (see Table 2). High-tech industries represented 3.6 percent of total employment (see Figure 2) and 15 percent of manufacturing employment in 1993 (see Figure 3). High-tech manufacturing lost 294 jobs between 1989 and 1993 (see Table 2). However, high-technology manufacturing is limited in San Antonio; in fact, employment in all of its top five high-tech manufacturing sectors combined does not exceed that of the highest sector in any of the other Texas metro areas. As observed in Table 2, the major high-tech manufacturing industry in San Antonio is Aircraft Production (SIC 3721), which employed 1,750 in 1993, twice as much as the next largest, Semiconductors (SIC 3674), which employed 750 people. There were no changes in employment in these two sectors between 1989 and 1993 (see Table 2). Much of San Antonio's high technology involves medical and biomedical research, which is classified as a service. In fact, the largest high-tech sector in this area was Commercial, Physical, and Biological Research (SIC 8731), which employed 3,047 people in 1993, representing a gain of 1,237 jobs from 1989. There was a total gain of 5,962 jobs in the high-tech service sector in San Antonio metro area between 1989 and 1993 (see Table 2).

We interviewed two firms in San Antonio, one in the Aircraft (SIC 3721) industry, and one that produces Semiconductors (SIC 3674). Company A, which manufactures airplanes, located in San Antonio because of its low labor costs and the availability of trained workers (from the many U.S. Air Force bases located in the area). Company B, a semiconductor company, located in San Antonio because the Austin labor market was already saturated and because there was another chip manufacturer already in San Antonio (AMD, now SONY). Additionally, San Antonio is a nice place to live.

Section 4
Empirical Analysis and Econometric Results

In this section we present (1) a description of our original data base of manufacturing establishments[22] in high-technology industries (2) a general description of the characteristics of our sample, and (3) results from our econometric models.

Data

Our original data base of 1,772 establishments in high-technology[23] industries came from the 1995 edition of the *Directory of Texas Manufacturers* (DTM), which is published annually by the Bureau of Business Research.[24] This original data includes *DTM* information on the top five 4-digit high-technology SIC codes by both volume of employment and number of firms in the five metropolitan areas of Austin, Dallas, Fort Worth, Houston, and San Antonio (see Table 5 in Appendix C for a list of the selected SIC codes by metropolitan area).

The empirical part was performed in two phases. During the first phase, conducted in the summer of 1996, we interviewed CEOs and managers at 23 high-technology firms in Austin, Dallas, Fort Worth, Houston, and San Antonio (see Table 6 in Appendix C for a list of the interviewed companies). The companies were carefully selected to comprise a representative sample of the population of high-tech companies; thus, we chose companies in different sectors and of different sizes. At the end of each interview, we left a questionnaire and a self-addressed envelope with the interviewees; we also made a written summary of our conversations with them. The purpose of the interview process was twofold. First, we wanted to pre-test early

[22] While "firm" is appropriate in the theoretical section of this paper, in the empirical section we should strictly be speaking about "establishment" instead of "firm." According to Audretsch (1995), an establishment can either be an independently owned legal entity, in which case it is also an enterprise (firm), or it can belong to a separate legal entity, in which case it is a branch or subsidiary of some enterprise. After warning the reader about this distinction, we freely interchange these terms in this section.

[23] As previously indicated, we used Markusen et al.'s (1986) selection of high technology SIC codes based on a relatively higher proportion of skilled labor in these SIC codes (see Appendix A).

[24] The *DTM* covers more than 90 percent of establishments with more than 10 employees in Texas, and more than 50 percent of those establishments with fewer than 10 employees. Because we expect to find most innovative high tech firms in establishments with at least 10 employees, the *DTM* is an excellent data base for our study.

versions of the questionnaire; many changes in the survey instrument were made as a result of this pre-test activity. Second, the process helped us formulate and interpret our hypotheses on the connection between innovations, networks, and location.

The second phase involved mailing questionnaires to 1,772 high-technology establishments[25] in the fall of 1996. The target respondent was the CEO (president) or general manager. We selected these individuals based on information gathered from the field interviews indicating that they would have the broadest knowledge about both customer/supplier relationships and about their firm's new products and processes. Questions were grouped into four categories: (1) their most important suppliers, (2) their most important customers; (3) other organizations important to them which are neither customers nor suppliers, and (4) location. A total of 374 completed questionnaires were returned (21 percent response rate). Responses were very close to their proportions in the population of high-tech firms by metropolitan area (see Table 7 in Appendix C). Standard research methods were used in an attempt to maximize the response rate to the questionnaire survey. We employed the total design method (TDM), a technique designed to produce a minimum of 40 percent response rate for mail surveys (Dillman 1978). This technique has resulted in successful response rates in recent studies on the high-technology industry (Lyons 1994). The fundamental element of TDM is a sequence of mailings and follow-ups designed to increase response rate. Our survey involved three mailings:

(1) A letter explaining the content and purpose of the survey along with the questionnaire and a stamped, addressed return envelope were sent to the 1,772 sample establishments in November 1996.

(2) 7 days later, a postcard thanking respondents and reminding nonrespondents to return questionnaires was sent.

(3) 21 days after the initial mailing, a letter and another copy of the questionnaire were sent to all the establishments in our data base.

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[25] We also sent the questionnaire to 100 Japanese establishments in Texas (see Appendix D), but did not have a good response (only 19 answered it), so we did not use this information. We selected these establishments from a list of 200+ Japanese firms in Texas obtained from the Japan External Trade Organization. In 1996, we called each firm and found that only 100 of them were *manufacturing* in Texas (many only have sales offices in the state).

Although TDM involves a fourth mailing of a letter and replacement questionnaire to nonrespondents by certified mail (49 days after the initial mailing), due to time and funding restrictions this step was not performed. To further increase the response rate, we were also very careful in assuring the confidentiality of firms' responses; in fact, it was a blind questionnaire in which *we* were not able to identify the respondent. Moreover, in the letter accompanying the questionnaire, as an incentive for them to respond, we promised to send respondents a summary of the results and a copy of the complete report if they request it.

General Description of our Sample

Most of the 374 manufacturing establishments that responded to our questionnaire were small firms—83 percent have fewer than 100 employees and 95 percent have fewer than 500 employees (the official cut-off point for a firm to be defined as a small firm by the Small Business Administration). More striking is the fact that 49 percent of them have fewer than 20 employees.[26] Despite being small, most were independent firms instead of branch plants. Of the 369 firms that responded to this question, only 16.5 percent indicated that they were branch plants. Furthermore, most of them were located in the Houston metropolitan area (40.1 percent), followed by the metropolitan areas of Dallas (26.7 percent), Fort Worth (13.9 percent), Austin (10.4 percent), and San Antonio (8.8 percent). A relatively high percentage (35.4 percent) of the firms started manufacturing in their respective metropolitan area in the 1980s.

As previously mentioned in the subsection on proxies to measure high-technology manufacturing, we divided our sample into two groups: those with at least 6 percent engineers and scientists in their plant (the high-tech group) and those with less than 6 percent engineers and scientists in their plant (the non-high-tech group). We did not observe significant differences between the two groups in terms of any of these variables; however, we did find significant differences between the two groups in terms of their participation in the international market.

[26] Saxenian (1994) reports a similar situation in Silicon Valley, a region populated by close to 3,000 electronic manufacturing firms in the 1970s, the vast majority of them small: 70 percent had fewer than 10 employees, and 85 percent had fewer than 100.

To account for random changes in firms' exports,[27] we asked: What percentage of your plant's production was exported in the *last five years*? and What percentage of your plant's revenue came from exports in the *last five years*? Most of the firms in our sample do export; in fact, only 28 percent do not export. For most of the non-high-tech firms, exports represented a relatively small percentage of total production—75 percent of these firms exported less than 10 percent of their total production in the last five years (see Table 8). On the contrary, as previous studies highlight (Hansen and Echeverri-Carroll 1996; Echeverri-Carroll et al. 1997), participation in the international market is very important for high-tech firms. About 70 percent of them reported that their exports represented more than 10 percent of their total production in the last five years. A similar difference between non-high and high-tech firms is observed when we asked firms what percentage of their total revenue in the last five years was generated by their exports.

Table 8. Number of sample firms by percentage of total production exported in last five years.

	0%	(0–10%)	[10–40%)	≥40%	Total
High tech[1]	20	34	78	45	177
Non-high tech[2]	78	51	33	12	174
Total	98	85	111	57	351

[1] Defined as firms in which at least 6% of employees are engineers and scientists.
[2] Defined as firms in which less than 6% of employees are engineers and scientists.

The Model and Econometric Results

This subsection describes statistical research on the innovative performance of our sample firms. Our main objective is to better understand how a high-technology firm's innovations (in

[27] Firms may export one year but may not export the following year, or they may export a large amount one year due to unpredictable circumstances when normally they export only a small percentage of their total production.

both product and process) are affected by two factors: (1) the quality of its relationships with other firms, mainly with its most important customers and suppliers and (2) the quality and access to *local* sources of knowledge such as technicians from the local area and engineers and scientists from local universities or local firms.

We used the basic *logit regression model* to account for the binary outcome variables which indicate innovative performance. Following the general notation of Hosmer and Lemeshow (1989), we write the logit model as

$$\ln\left[\frac{\pi_n}{1-\pi_n}\right] = \sum_{K=0}^{K} \beta_{K,c} X_{K,g}$$

where the outcome parameters are the natural logarithm (ln) of the odds ratio ($\pi/(1-\pi)$) of the binary outcome Y_n, the X_k are observed scores on K independent variables,[28] and the β_k are linear regression coefficients. We typically include the constants $X_{0,n} = 1_n$ so that the β_0 is a usual intercept term. Each of these indices gives estimates of the independent effects for the predictor variables in the model. The parameters of the standard logit model can be interpreted directly or after transformation to a probability $\pi(x)$:

$$\pi(x) = \frac{e^{\sum \beta_{K,c} X_{K,c}}}{1 + e^{\sum \beta_{K,c} X_{K,c}}}$$

where $\pi(x)$ is the conditional probability that the outcome is present and it is denoted by $P(Y = 1|\mathrm{x}) = \pi(\mathrm{x})$ where the vector x'= (x_1, x_2, x_3,......,x_k) is a collection of *k* independent variables. In the following two subsections, we describe how we tested the capacity of *two sets*

[28] In several cases, we transformed variables which originally had multiple levels into binary dummies. The rationale is that respondents are more likely to be able to sort themselves accurately into two groups (those who considered a contract longer than one year important or not important, for example) than into five. This procedure did not affect the results.

of variables to predict innovative performance: (1) a set of variables describing the organizational structure of the relationship with main customers and suppliers and (2) a set of variables describing characteristics of the city (including sources of knowledge spillovers).

Customer/Supplier Networks and Innovations[29]

Because many companies supply their customers with several different products and buy different inputs from suppliers, and because their relationship with customers and suppliers differs by product, survey respondents were asked to provide answers regarding only their *most important* customers and suppliers.[30] We use Helper's (1987, 1990, 1991) "voice relationship" as a proxy for relationships that are established in a network system. She suggests that a useful way to classify a supplier/customer relationship is according to the methods used to resolve problems that arise between the parties. In an "exit" relationship, a customer that has a problem with a supplier finds a new supplier. In a "voice" relationship, the customer works with the original supplier to resolve the problem. Voice relationships have two dimensions: information exchange and commitment. As Helper (1991) points out, at the lowest level, the only information exchanged is the price of off-the-shelf products; this is the market described in economics textbooks. At the highest level, customer and supplier provide continuous feedback and suggestions for improvement of each other's operations; there is a frequent exchange of *technical* information. Commitment refers to the supplier's degree of certainty that the customer will continue to buy its products for some length of time.[31] According to Helper (1993), in a voice relationship, contracts are: (a) longer than one year, (b) open ended (they can be altered when the circumstances change), and (c) involve providing detailed breakdown of process steps.

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[29] Although we asked questions about the kind of relationships that firms have with other firms which were not suppliers or customers (for instance, competitors), we found little evidence that firms in our sample have networking relationships with these firms that are significant in their innovations. Thus, the empirical analysis in this section focuses only on the relationship with firms which were either customers or suppliers to our sample firms.

[30] In the interviews, we found that firms considered their most important suppliers those that supply a high-volume or expensive input, or have a monopoly position in the industry. Firms considered their most important customers those that are large (they buy in high volume) or strategic (highly visible), or that pay for product development.

[31] For instance, if the supplier experiences a problem with cost or quality, the purchasing firm will attempt to work *together* with the supplier before switching to another supplier.

We adopted Helper's voice concept to measure the degree of networking relationships of surveyed firms with their main suppliers and customers. Thus, we asked sample firms whether their contracts with their main suppliers/customers were for longer than one year and whether they were willing to alter the contract if something unexpected occurred (a measure of the flexibility of the contract). We did not ask whether suppliers/customers provide detailed breakdown of process steps; instead, our interest was in the *frequency* with which *technical* information was mutually exchanged since it has a more direct effect on innovations.[32] Firms may maintain frequent exchange of information with most of their suppliers/customers, but that may be sales and ordering information, not engineering and scientific information. Our questions focus on the exchange of engineering and technical information since it is this kind of information that would affect innovations.

Innovations and Relationships with Customers

A response that the relationship with most important customers was important in their innovations is considered as the key outcome variable in the first logit model. The variable termed $\mathbf{Y}_{bi}$ is scored as a unit value if the firm answered that the relationship with its most important customers was very important in its innovations. $\mathbf{Y}_{bi}$ is scored as a 0 if the firm answered that this relationship was not important in this function. In measuring the importance of the relationship with customers in the innovation performance of a firm, we consider both product and process innovations. Thus, the subindex "i" refers to whether this relationship is important in (a) the development and commercialization of new products (proxy for product innovations) or (b) reducing manufacturing and development cycles (proxy for process innovations). Both types of relationships will be affected by the same independent variables. We use the following logit regression model:

[32] It is important to recognize that the length of the contract does not give any indication of the volume of *technical* information exchanged between firms. In fact, many of the largest U.S. auto makers have had arm's length relationships with the same suppliers for many years, yet each firm knows very little about the manufacturing process of the other firm. There is an *implicit* agreement that as long as the suppliers continue to be the lowest bidder, there will be a renewal of the contract next year.

$$(1)\ \Pr(Y_{bi}=1) = F\ (\text{bpinfo, brinfo, cont, flexc, bloc})$$

Table 9 presents the description of the dependent variables and the five explanatory variables included in logit model 1. We hypothesize that a firm will be more likely to value the relationship with a customer as very important in the task of developing new products or processes if the networking between them is strong. A networking relationship involves three components. First, it requires frequent (daily/weekly) exchange of technical (engineering and scientific) information between firms. Repeat contacts increase knowledge about the partner firm (relation-specific expertise) which considerably shortens the lead time necessary for the development of new products and processes. Second, networking relationships involve long-term (longer than one year) contracts. As pointed out by Teece (1981), by establishing long-term relationships, firms facilitate the transfer of tacit (experiential) knowledge of the sort frequently involved in highly *uncertain* innovation processes—knowledge which is too difficult for arm's length exchange partners to transfer. Third, networking relationships involve flexible contracts. In a market characterized by short product cycles, the ability to change contracts when unexpected events occur would play a key role in speeding up innovations.

If networks are more important than arm's length relationships in high-tech firms' innovations, we would expect that most predictors (coefficients) in logit equation 1 would be important and different from zero. Results presented in Table 10 show support for this hypothesis. As indicated by the significance of the respective coefficients and the significance of the models in columns 1 and 3, high-tech firms are more likely to consider a relationship with a customer important in developing new products (proxy for product innovations) or reducing manufacturing and development cycles (proxy for process innovations) if the relationship involves *providing* to customers technical information on a daily or weekly basis and maintaining flexible, long-term contracts with them. As expressed by CEOs and managers in our interviews, customers matter because the firms want to develop only products that can be successfully commercialized.

Table 9. Description of dependent and independent variables for logit model 1.

Dependent variables

Y_{bi}=	is a dichotomous dependent variable with a value of 1 if a firm responded that its most significant buyers (customers) were very important in the process of commercializing and developing new products and with a value of 0 if the answer was they were not important in this task. The subindex "i" refers to whether it is product or process innovations.

Independent variables

bpinfo	buyers provide firm with engineering or technical information daily or weekly=1, otherwise=0.
brinfo	firm provides buyers with engineering or technical information daily or weekly=1, otherwise=0.
contb	firm has a contract longer than one year with most important buyers=1, otherwise=0.
flexcb	most important buyers were willing to alter contract if unexpected events occur=1, otherwise=0.
bloc	most important buyers were located in the same metropolitan area=1, otherwise =0.

Surprisingly, frequently *receiving* technical information from its customers does *not* have an important effect on a high-tech firm's *process* innovations (see large p-value of variable bpinfo in column 3 of Table 10). The effect of this flow of information on *product* innovations *is* important, but has an unexpected result. The negative, but significant coefficient for bpinfo (column 1 of Table 10) indicates that high-technology firms that do not receive frequent technical information from their customers have a higher probability of considering a relationship with their customer as very important in the process of developing and commercializing *new products* than high-tech firms which receive this information frequently.

Table 10. Logit results: dependent variable Y_{bl} = importance of buyers in product and process innovation.

	Column 1	*Column 2*	*Column 3*	*Column 4*
	Product innovations		Process innovations	
	High tech[1]	Non-high tech[2]	High tech[1]	Non-high tech[2]
Constant	−2.099 *	−0.965 **	−2.897 *	−1.733 *
	(0.599)	(0.559)	(0.682)	(0.590)
brinfo	2.338 *	1.148 **	1.343 *	0.838
	(0.801)	(0.638)	(0.611)	(0.598)
bpinfo	−2.021 *	0.204	0.069	0.929
	(0.840)	(0.672)	(0.660)	(0.639)
contb	1.054 *	1.130 *	1.658 *	0.745 **
	(0.465)	(0.451)	(0.429)	(0.450)
flexcb	2.151 *	−0.223	1.548 *	0.679
	(0.592)	(0.562)	(0.651)	(0.559)
bloc	0.703	−0.069	0.348	0.478
	(0.526)	(0.416)	(0.512)	(0.406)
Sample size	135	123	136	128
−2 log L	38.735	18.587	44.571	25.058
p	0.0001	0.0023	0.0001	0.0001

Note: Standard errors are in parentheses.

* Significant at the 5 percent level.

** Significant at the 10 percent level.

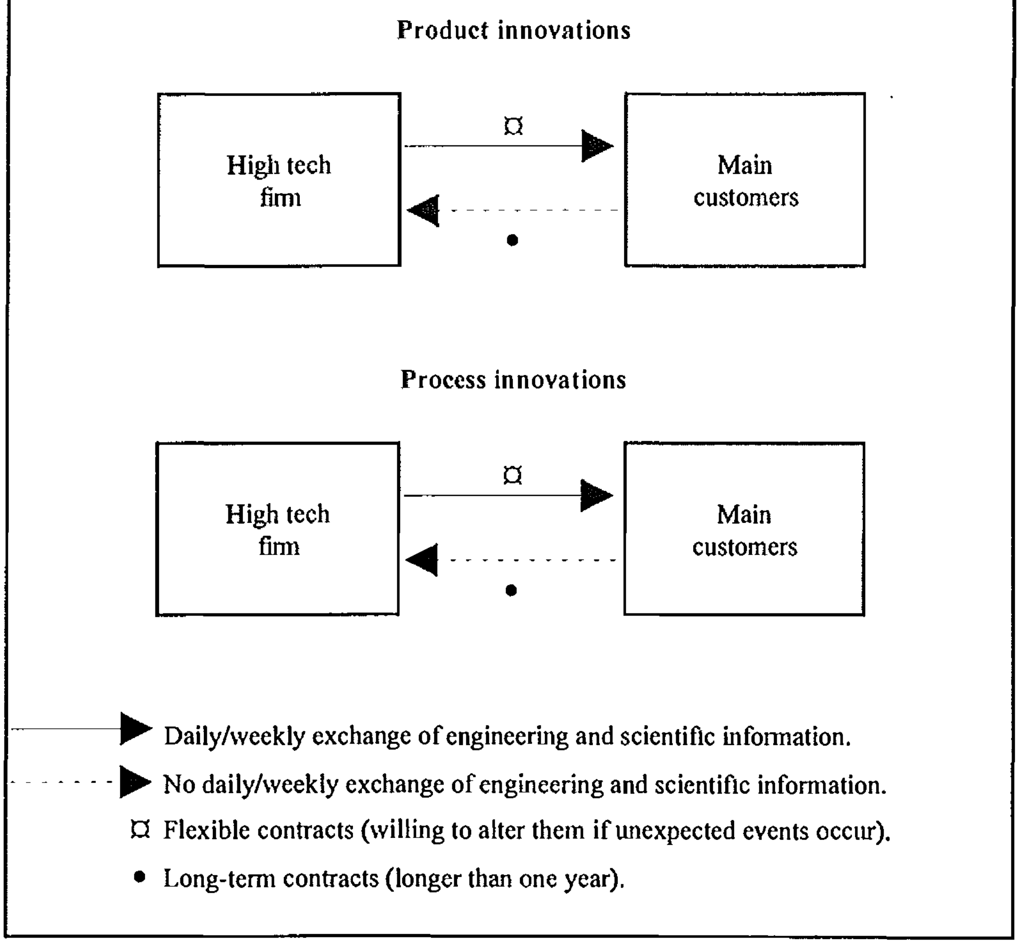
[1] Defined as firms in which at least 6% of employees are engineers and scientists.

[2] Defined as firms in which less than 6% of employees are engineers and scientists.

In sum, high-technology firms in Texas show evidence that networking relationships are important in their product and process innovations as indicated by the importance of long-term, flexible contracts and the engineering and scientific information that they provide to their customers. However, these seem to be asymmetric networks in which high-tech firms *provide* more frequently than they *receive* technical information in developing new products and processes (see Figure 4).

Large p-values for the coefficients of variable **bloc** (columns 1 and 3 in Table 10) indicate that the location of the customer does not help explain whether the high-tech firm considers its relationship very important in either its product or process innovations. This result is consistent with what managers expressed in our interviews: that their most important customers were scattered all around and not necessarily concentrated in the same metropolitan area as themselves.

Figure 4. Asymmetric networking relationships with *customers* in product and process innovations.



Innovations and Relationships with Suppliers

A response that the relationship with its most important suppliers was important in a firm's innovations is considered as the key outcome variable in the second logit model. The variable termed $\mathbf{Y_{si}}$ is scored as a unit value if the firm answered that the relationship with its most important suppliers was very important in its innovations. $\mathbf{Y_{si}}$ is scored as a 0 if the firm answered that this relationship was not important in this function. In measuring the importance of the relationship with suppliers in the innovation performance of a firm, we consider again both product and process innovations. Thus, the subindex "i" refers to whether this relationship is important in (a) the development and commercialization of new products (proxy for product innovations) or (b) reducing manufacturing and development cycles, not necessarily of new products (a proxy for process innovations). Both types of relationships will be affected by the same independent variables. We use the following logit regression model:

$$(2)\ \Pr(Y_{si}=1) = F(\text{spinfo, srinfo, conts, flexcs, sloc})$$

Table 11 presents the description of the dependent variables and 5 explanatory variables included in logit model 2 and Table 12 presents results of logit model 2. As indicated by the significance of the respective coefficients in column 3 of Table 12, the probability that a high-tech firm would value the relationship with a supplier as very important in its *process innovations* (in reducing manufacturing and development cycles) is determined by the flexibility of the contract with the supplier and by the technical information that it provides to the supplier. The coefficient for the variable **sloc** shows a large p value, indicating that the location of the supplier was not important in explaining whether a high-tech firm considers their relationship as very important in its process innovations. This last result is consistent with what was suggested by the managers we interviewed: that their most important suppliers were scattered all around.

Table 11. Description of dependent and independent variables for logit model 2.

Dependent variables

Y_{si}=	is a dichotomous dependent variable with a value of 1 if a firm responded that its most significant suppliers were very important in the process of commercializing and developing new products and a value of 0 if the answer was negative. The subindex " i" refers to whether it is product or process innovations.

Independent variables

spinfo	suppliers provide engineering or technical information to firm daily or weekly=1, otherwise=0.
srinfo	firm provides engineering or technical information to suppliers daily or weekly=1, otherwise=0.
conts	firm has a contract longer than one year with most important suppliers=1, otherwise=0.
flexcs	most important suppliers willing to alter contract if unexpected events occur=1, otherwise=0.
sloc	most important suppliers located in the same metropolitan area=1, otherwise=0.

The significant, but negative coefficient for variable **sloc** (see column 1 in Table 12) indicates that the location of the main suppliers matter in product innovations, but it is their low concentration in the metropolitan area which is important. This is an indication that in product innovations, the relationship with local suppliers is not the only important one. In the relationship with suppliers, only the variable **flexes**, which measures the flexibility of the contract, is significant in a high-tech firm's product and process innovations (see Figure 5).

Table 12. Logit results: dependent variable Y_{si} = importance of suppliers in product and process innovations.

	Column 1	*Column 2*	*Column 3*	*Column 4*
	Product innovations		Process innovations	
	High tech[1]	Non-high tech[2]	High tech[1]	Non-high tech[2]
Constant	–0.660 (0.447)	–0.490 (0.483)	–1.497 * (0.511)	–0.980 * (0.484)
srinfo	0.779 (0.569)	–1.163 (0.710)	1.102 ** (0.577)	0.502 (0.566)
spinfo	0.063 (0.605)	1.778 * (0.689)	0.081 (0.612)	0.399 (0.554)
conts	0.064 (0.402)	0.074 (0.482)	0.104 (0.409)	0.769 (0.480)
flexes	0.942 ** (0.507)	–0.049 (0.507)	1.609 * (0.554)	0.510 (0.493)
sloc	–0.903 * (0.417)	–0.778 (0.497)	–0.153 (0.423)	0.343 (0.451)
Sample size	133	123	134	123
–2 log L	14.718	11.143	21.917	10.429
p	0.0116	0.0486	0.0005	0.0640

Note: Standard errors are in parentheses.

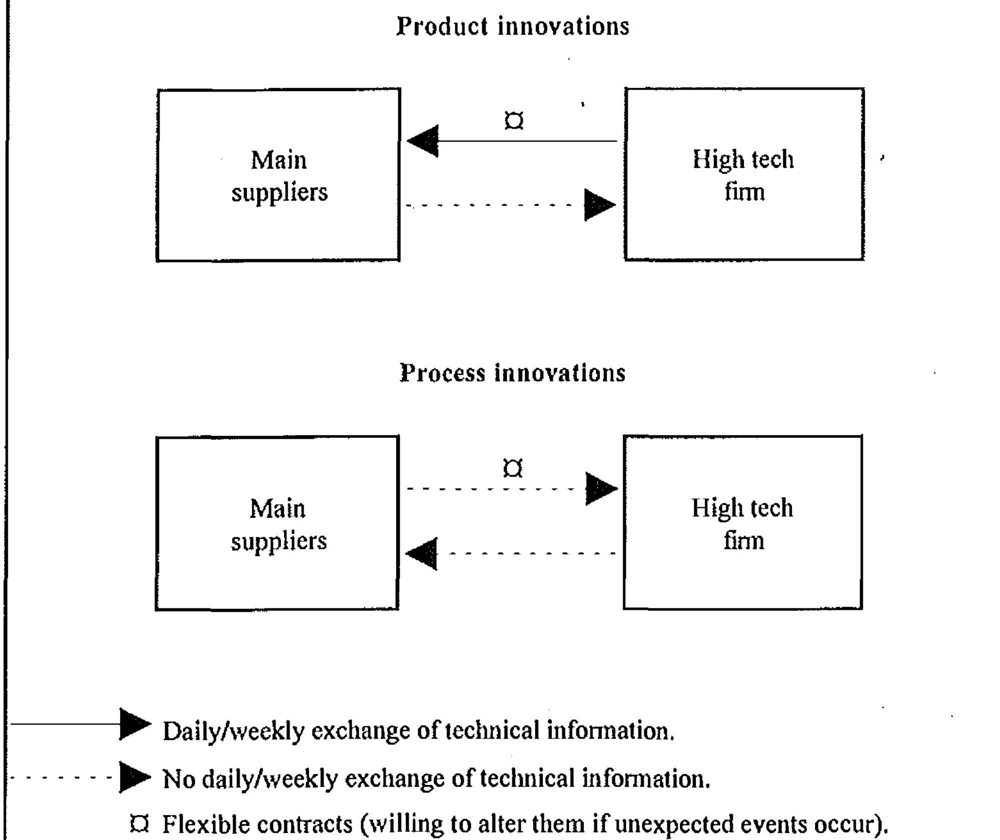
* Significant at the 5 percent level.

** Significant at the 10 percent level.

[1] Defined as firms in which at least 6% of employees are engineers and scientists.

[2] Defined as firms in which less than 6% of employees are engineers and scientists.

Figure 5. Arm's-length relationship with *suppliers* in product and process innovations.



In sum, the relationship with suppliers in developing new products and processes is more characteristic of arm's length relationships than of network systems as indicated by the fact that there is little exchange of technical information with suppliers and a preference for short-term contracts with them in developing new products and processes.

Are there Differences Between Non-High-Tech and High-Tech Firms?

Although in the previous subsection we concentrated on the innovative performance of high-technology firms (since most innovations should occur within this group of firms), we observe some differences between the high-tech and non-high-tech groups in terms of their networking relationships with suppliers and customers. Networking relationships with customers and suppliers are more important in the innovation of products and processes of high-tech than of non-high-tech firms as indicated by the large p-values that most coefficients show in the logit regression for the non-high-tech firm group (see columns 2 and 4 in Tables 10 and 12). We also observed some similarities between the two groups. Both high- and non-high-tech firms, for instance, show similar locational patterns for their most important suppliers and customers: they tend to be scattered all around instead of concentrated in a particular metropolitan area (see Table 13).

Table 13. Location of most important suppliers and customers.

	Suppliers		Customers	
	Concentrated in the metro area	Scattered all around	Concentrated in the metro area	Scattered all around
	Number of firms			
High-tech firms	49	119	33	137
Non-high-tech firms	51	110	63	97
Total	100	229	96	234

As policymakers struggle to attract high-tech firms (because of the expected implications for innovations and economic growth), the issue of what benefits from the urban area can *uniquely* attract or encourage the development of high-tech firms becomes relevant. Table 14 shows that the quality of life is the most important consideration for the performance of high-tech firms (average response of 3.69), but it is also the most important consideration for the performance of non-high-tech firms (average response of 3.56). Similarly, central location for product distribution to other areas is an important consideration for high-tech firms (average response of 3.10); however, it is also an important consideration for non-high-tech firms (average response of 3.31). In fact, t-tests reject the hypothesis that there are differences between the means for these two groups in these two variables at the 0.05 level.

Table 14. For high-tech and non-high-tech firms, mean responses on importance of "urban characteristics" on performance of firms.

	n	Non-high tech	High tech	Pro > |T|
Foci for majority of your sales/purchases	353	3.19	2.60	0.0000
Central location for product distribution to other areas	361	3.31	3.10	0.1357
Accessibility to frequent flights for your employees	344	2.24	2.67	0.0735
Presence of other firms that help you attract skilled labor	354	2.73	3.02	0.0245
Establishments supplying temporary help	360	2.08	2.42	0.0085
Other specialized business services	357	2.63	2.86	0.0763
Information from local universities' scientists and professors	355	2.06	2.32	0.0404
Local universities provide engineers and scientists	357	1.94	2.36	0.0006
Local firms are a source of scientists/engineers	353	2.09	2.58	0.0001
Local area is a source of technical personnel	356	2.69	3.17	0.0002
Quality of life of the local area	353	3.56	3.69	0.2391

The urban factors that are unique to high-tech firms are (a) the presence of other high-tech firms to attract skilled labor and (b) the availability of local technical personnel. In fact, t-tests do not reject the hypothesis that there are differences between the means for these two groups in these two variables at the 0.05 level. The uniqueness of these urban factors is consistent with the opinion of the managers and CEOs that we interviewed, who maintain that the presence of other high-tech firms is important not so much as a direct source of engineers and scientists, but because of their indirect effect of reducing the likelihood that a skilled worker will suffer a long bout of unemployment. All the high-tech firm interviewees said they look for expertise, in particular for engineers and scientists, *wherever* it is available and are not necessarily constrained in this by geographical barriers. On the contrary, most of them said that they hire most of their technical personnel *locally.* In fact, most concerns of high-tech firms in the Austin metro area, where high-tech employment has grown rapidly in the 1990s, are based on the scarcity of local *technical personnel* (see Kay 1996).

Not all high-tech firms conduct research and development which leads to innovations. Some of them assemble high-tech products whose R&D was conducted at headquarters located elsewhere. Because economic development benefits perceived from high-tech firms are mainly associated with the implicit assumption that they are highly innovative activities, we must ask whether innovative high-technology firms tend to rely mainly on local sources of knowledge.

Does Geography Matter for Innovative High-Technology Firms?

It makes sense to assume that firms which establish long-term networking relationships that involve a continuous exchange of engineering and scientific (technical) information with suppliers and customers may gain a competitive advantage by locating close to them. Besides delivering products faster, they can establish more frequent communication between manufacturing facilities, and, as already indicated, frequent communication over a long period of time would have a positive effect on innovations by allowing the development of relation-specific expertise (knowledge). To measure the effect of spatial proximity on innovations, one has first to recognize that most of the knowledge is neither located inside a company nor readily available for purchase (Powell et al. 1996). Knowledge is embodied *in people* who communicate informally and in this process exchange "free" ideas. A critical issue in assessing the relationship between innovations and knowledge externalities is that this informal exchange of knowledge is difficult to measure. However, following Arrow (1962) and Krugman (1991a), we believe that while it is not possible to directly measure the extent to which this informal exchange of ideas occurs, it is possible to identify the main sources of knowledge for firms. We make the crucial assumption that knowledge is more important and embodied, at least to some degree, in skilled labor: engineers, scientists, professors, and technicians.

We ask two critical questions. *(1) Which organizations are a source of skilled labor for high-technology firms?* We agree with the NSF (1996) study that networking relationships with customers and suppliers is perhaps the most important source of knowledge for innovations; however, we also test the importance of other sources of skilled labor, such as other high-technology firms, universities, and business services. *(2) Are these organizations located mainly in the same metropolitan area where the high-tech firm is?* A body of literature suggests that the most important sources of knowledge are local; thus, high-tech firms hire engineers and scientists mainly from local firms and universities and technical personnel from local technical institutes. This argument is based on the assumption that knowledge (as opposed to information) is expensive to transfer across long distances (Audretsch and Feldman 1996). Under this assumption, the networking of firms within a city becomes the primary source of knowledge for innovations. This is the scenario described by Saxenian (1994) in Silicon Valley, where most strategic relationships between high-tech firms are local and where the intensity of these local networks gives these firms the ability to come out with a constant stream of new products.

A second body of literature suggests that the main sources of knowledge for innovations are not concentrated in the same city in which the high-tech firm is located. Krugman (1991) suggests that innovative firms may agglomerate for reasons other than the availability of knowledge sources, such as the quality of life or availability of major inputs (which are also the reasons why non-high-tech firms agglomerate). The fact that most important suppliers and customers for high-tech firms in our sample are scattered all around certainly supports the view that at least knowledge created in the relationship with these firms is not local. Previous empirical studies for high-tech firms in Texas also suggest that some high-tech firms' most strategic relationships are not established with local firms (Hansen and Echeverri-Carroll 1997).

To test whether the main sources of knowledge for innovations are local or not, we divide our sample of high-technology firms[33] into two groups: (a) high-tech firms which are innovating faster than their industry group, and (b) high-tech firms that are innovating at a slower pace than

[33] A firm which answered that 6 or more percent of its employees were engineers and scientists.

their industry group. Our models are built with the objective of examining the influence of two factors, (a) characteristics of cities and (b) relationships with main customers/suppliers, on the probability that a high-tech firm innovates (in products and processes) at a pace above its industry group average. These effects on innovations in high-tech firms are estimated separately for product and process innovations. Equation 3 estimates the probability that a high-tech firm will develop and bring to market *new products* faster than firms in its industry group. The variable termed Y_{pi} is scored as a unit if the firm answered that it was *above* its industry group average when comparing the average number of products it developed and brought to market with that of its industry group in the last two years. Y_{pi} is scored as a 0 if the answer was that it was *below* its industry group average. The probability that a high-tech firm will be above its industry average in product innovations is estimated by the following logit regression model:

$$(3)\ \Pr(Y_{pi}=1) = F\ (\text{organizational} + \text{locational variables})$$

Table 15 presents a description of the predictor variables included in logit model 3. According to Marshall (1920), a city offers a firm benefits associated with three kinds of variables: (1) technological spillovers, (2) a pooled market of workers with specialized skills, and (3) availability of specialized inputs and services. Krugman (1991) mentions a fourth reason, suggested much earlier by Weber (1929) and Isard (1956): the size of the market and easy transportation and distribution of products. Thus, we asked firms in our sample to evaluate the relative importance of these urban characteristics in the performance of their plant on a scale from 1 (not important) to 5 (very important). In running the logit regression, we transformed these variables which originally had multiple levels into binary dummies with a value of 1 (very important) if the response was either 4 or 5 and a value of 0 (not important) if the response was either 1, 2, or 3.

Table 15. Independent variables: organizational and locational variables.

Organizational Variables

(1) bprodin: it has a value of 1 if a firm responded that its relationship with buyers was important in developing and commercializing new products and a value of 0 otherwise.

(2) sprodin: it has value of 1 if a firm responded that its relationship with suppliers was important in developing and commercializing new products and a value of 0 otherwise.

(3) bproccin: it has a value of 1 if a firm responded that its relationship with buyers was important in reducing manufacturing and development cycles (proxy for process innovations) and a value of 0 otherwise.

(4) sproccin: it has a value of 1 if a firm responded that its relationship with suppliers was important in reducing manufacturing and development cycles (proxy for process innovations) and a value of 0 otherwise.

*Locational Variables**

a. Scale of the city

(5) foci for the majority of a firm's sales/purchases (MKS)

(6) the presence of other specialized business services (SBS)

(7) establishment supplying temporary help (ETH)

(8) quality of life (QL)

b. Transportation

(9) a central location for the distribution of products (CLD)

c. "Local" technical externalities

(10) presence of other firms help you attract skilled labor (POF)

(11) information from local universities' scientists and professors (ILU)

(12) local universities provide engineers and scientists (LUE)

(13) local firms are a source of scientists and engineers (LFS)

(14) local area is a source of technical personnel (LAT)

d. "Non-local" technical externalities

(15) accessibility to frequent flights for your employees (AFF)

* The original question asked firms to evaluate, on a scale from 1 (not important) to 5 (very important), the contribution of the metropolitan area in which they were located to the performance of their plant. In the logit regression model, however, we transform these multilevel variables to binary ones. These independent variables have a value of 1 if the answer was either 4 or 5 and a value of 0 otherwise.

If Krugman's (1991) view is right, we expect to find that the probability for a high-tech firm to develop new products at a pace above its industry group is related *not* to the city as a locus of knowledge, but to the city as a locus of communication with other metropolitan areas where *external* sources of knowledge are located. On the contrary, evidence to support Audretsch and Feldman's (1996) hypothesis will be found if local sources of knowledge are the most important factor in determining whether a high-tech firm develops and commercializes new products at a pace faster or slower than the average in its industry group.

Our results, presented in Table 16, support the first hypothesis. As indicated by the significance of the coefficients and of model 3 (the most parsimonious model of the three that we estimated), a high-tech firm will have a higher probability of developing new products at a pace faster than the average for its industry group if (a) it maintains close relationships with suppliers in developing new products (variable named **sprodin**), (b) it maximizes access to external (non-local) sources of knowledge by locating in a city that provides frequent flights for its employees (variable named **AFF**), and (c) it maximizes access to technical personnel (a source of knowledge) by hiring some of them from outside the area (variable named LAT).

Equation 4 estimates the probability that a high-tech firm will reduce manufacturing and development cycles (a proxy for process innovations) faster than firms in its industry group. The variable termed $\mathbf{Y_{pr}}$ is scored as a unit if the firm answered that it was *above* its industry group average when comparing the average changes it has made to reduce its manufacturing and development cycles with those that firms in its industry group have made. $\mathbf{Y_{pr}}$ is scored as a 0 if the high-tech firm answered that it was *below* its industry group average. The probability that a high-tech firm will be above its industry average in *process innovations* is estimated by the following logit regression model:

$$(4)\ \Pr(Y_{pr}=1) = F\ (\text{organizational} + \text{locational variables})$$

Table 16. Logit model results: dependent variable Y_{pi}.

Variables	*Column 1* Model 1 B_k	*Column 2* Model 2 B_k	*Column 3* Model 3 B_k
Intercept	1.353 *	0.899	0.585
	(0.557)	(0.618)	(0.425)
Organizational variables			
bprodin		0.170	0.163
		(0.589)	(0.554)
sprodin		0.978	1.038 **
		(0.664)	(0.580)
"Local" variables			
Sales/purchases (MKS)	−1.090	−0.994	
	(0.679)	(0.695)	
Product distribution (CLD)	0.314	0.277	
	(0.671)	(0.701)	
Other firms (POF)	0.844	0.439	
	(0.799)	(0.884)	
Temporary help firms (ETH)	1.479	1.567	
	(1.010)	(1.018)	
Business services (SBS)	0.942	0.611	
	(0.674)	(0.732)	
Local professors/scientists (ILU)	−0.022	−0.012	
	(0.926)	(0.955)	
Universities provide engineers (LUE)	−0.484	−0.424	
	(1.006)	(1.122)	
Engineers from local firms (LFS)	0.073	0.127	
	(0.859)	(0.901)	
Local technicians (LAT)	−1.300 **	−1.457 **	−1.402 *
	(0.704)	(0.756)	(0.605)
Quality of life (QL)	−0.806	−0.625	
	(0.6647)	(0.696)	
"External" variables			
Frequent flights (AFF)	1.560 **	1.519	1.797 *
	(0.929)	(0.995)	(0.790)
n	91	86	86
−2 log–L	21.050	22.105	14.786
P	0.0329	0.0538	0.0052

Note: Standard errors are in parentheses.
* Significant at the 0.05 percent level. ** Significant at the 0.10 percent level.

Table 17. Logit model results: dependent variable $Y_{pr.}$

Variables	*Column 1* Model 1 B_k	*Column 2* Model 2 B_k	*Column 3* Model 3 B_k
Intercept	0.784	–0.105	0.646 **
	(0.547)	(0.683)	(0.372)
Organizational variables			
bproccin		0.276	
		(0.962)	
sproccin		2.560 *	1.968 *
		(1.091)	(0.704)
"Local" variables			
Sales/purchases (MKS)	–0.556	–0.147	
	(0.820)	(0.856)	
Product distribution (CLD)	0.672	0.216	
	(0.849)	(0.920)	
Other firms (POF)	1.202	1.404	
	(1.191)	(1.170)	
Temporary help firms (ETH)	–0.243	–0.614	
	(1.271)	(1.473)	
Business services (SBS)	1.463	0.928	
	(1.132)	(1.340)	
Local professors/scientists (ILU)	–0.746	0.013	
	(1.016)	(1.109)	
Universities provide engineers (LUE)	0.583	–0.591	
	(1.314)	(1.597)	
Engineers from local firms (LFS)	–1.986	–2.277	
	(1.597)	(1.763)	
Local technicians (LAT)	–0.160	–0.041	
	(0.953)	(1.060)	
Quality of life (QL)	0.587	0.737	
	(0.689)	(0.803)	
"External" variables			
Frequent flights (AFF)	0.894	0.220	
	(1.086)	(1.096)	
n	79	75	76
–2 log–L	9.519	18.388	9.526
p	0.5741	0.1433	0.0020

Note: Standard errors are in parentheses.
* Significant at the 0.05 percent level. ** Significant at the 0.10 percent level.

As indicated in Table 17 by the significance of the coefficients and model 3 (the most parsimonious model of the three that we estimated), the sources of knowledge for *process innovations* are strongly associated with one source: the involvement of suppliers in process innovation (**sproccin**). Thus, a high-tech firm has a higher probability to be above its industry group average in process innovations if it maintains a significant relationship with suppliers in this task.[34]

[34] Institutional factors other than customer/supplier relationships and access to knowledge from the sources we have considered here are often important in determining innovations. For example, the volume of internal research and development and the length of time in which the firm has been doing R&D are important determinants of innovations (Jaffe et al. 1993). We account for these effects indirectly, in the sense that internal R&D is strongly correlated with skilled labor in the factory (Grillinches et al. 1997). Thus, we expect that firms with a high proportion of skilled labor will have high correlations with other variables affecting innovations, such as R&D.

Section 5
Conclusions

High-technology studies conducted in the 1970s and early 1980s implied that the United States was developing a dual manufacturing economy with a spatial division of labor between regions: research and development in the Northeast and West and production plants in the Sunbelt states (Norton and Rees 1979; Malecki 1979, 1980a,b,c). Studies conducted at the Bureau of Business Research in the 1980s and published under the series title *Technology in Texas* cautioned policymakers that such a trend would cast into doubt the possibility that high-technology industries locating in Texas could generate dynamic economic growth (Campbell 1986; Campbell and Goodman 1986).

Is the high-technology industry locating in the region *innovating* or simply *assembling* high-tech products? How can a region develop or attract *innovative* high-technology firms? In designing policies to develop or attract innovative high-technology firms, policymakers must understand the factors that affect innovations. We argue that Japanese-style networks could positively affect the innovative performance of firms in industries (such as high technology) that are marked by changing demand conditions for two reasons: (1) knowledge networks create "network-specific expertise," which speeds up product and process innovations (Aoki 199n), and (2) spatial proximity, usually assumed for Japanese networked firms, could facilitate the exchange of tacit information, a key input in innovations.

In studying the relationship between Japanese-style networks and innovations in high-technology firms, we considered conceptual issues. First was the issue of defining a high-technology *industry*. After reviewing strengths and weaknesses associated with different classifying criteria, we opted for Markusen, Hall, and Glasmeier's (1986) high-technology definition, which is based on the percentage of "human capital" jobs in an industry. (Human capital jobs include engineers, technicians, scientists, mathematicians, or some combination thereof.) Using this criterion, Markusen et al. (1986) selected 100 4-digit industries listed as high technology.

This definition offers several competitive advantages. In particular, human skills highly correlate with other indicators of "technological" performance, such as R&D (Berman et al. 1994), the stock of capital, information intensity, and, most important for our study, innovations (Audretsch and Feldman 1996). In fact, human capital is associated with positive effects on economic development at the national (Romer 1986) and regional (Glaeser 1994, Lucas 1988, Rauch 1991, Krugman 1991) levels *because* of its positive impact on innovations.

Using Markusen et al.'s (1986) industry classification, we compared trends in high-technology employment by industry in the "traditional" U.S. high-technology regions—Silicon Valley, Route 128, Southern California, and Research Triangle Park (RTP)—and in Texas between 1989 and 1993. In Texas, we studied the high-tech industry in the metropolitan areas of Austin, Houston, San Antonio, Fort Worth, and Dallas. To determine employment trends in high-technology *services,* we used Vinson and Harrington's (1979, cited by Markusen et al. 1986) list of high-technology industry service-related SIC codes, as determined by product sophistication. We used employment data from *County Business Patterns*, the only employment data available by detailed SIC industrial classification at the county level. Data show job gains in the high-technology *service* industries in all of the considered high-tech regions between 1989 and 1993. However, job gains in *manufacturing* were experienced only by the high-tech industries in RTP, Houston, and Austin. Despite the importance usually attributed to the high-tech sector in these regions, the degree of economic diversification of these regions is significant: the participation of high tech in total employment in any of the regions considered in this analysis never exceeds 15 percent.

High-tech employment in both manufacturing and services in the five largest metropolitan areas in Texas was 435,512 in 1993. Houston has the largest participation with 149,831 high-tech jobs; closely followed by Dallas, 145,454; then Fort Worth, 63,027; Austin, 53,670; and finally San Antonio, 23,530. Each metropolitan area tends to specialize in certain high-tech manufacturing sectors—aircraft production in Dallas, Fort Worth, and San Antonio; telecommunications in Dallas; semiconductors and computers in Austin; and oil and gas technology in Houston—and in certain high-tech services, with Austin and Houston specializing in engineering services, Dallas in computer and data processing services, Fort Worth in accounting services, and San Antonio in biotechnology research. This analysis indicates that the Texas high-tech industry is now a major player in the U.S. high-tech sector. This observation, together with Markusen et al.'s (1986) finding that the high-technology industry is highly innovative, makes Texas an excellent case to study innovations in high-tech firms.

Specialized Supplier Networks as a Source of Innovative Advantage

What kind of industrial organization will be more conducive to innovations? That will be determined by the type of market. For firms competing in markets characterized by short product cycles, a *network industrial organization*, such as the one associated with the Japanese firm, introduces new products faster than an arm's length organization (Aoki 199n). The success of Japanese firms in rapidly developing new products is often attributed to their ability to coordinate design and manufacturing effectively with suppliers (Aoki 19n, Helper 199n; Dyer 199n). By involving suppliers early in product innovation, Japanese firms avoid the waste characterized by mismatches in the fitting of parts within a new product (Womack et al 199n). Supplier engineers and customer engineers develop relation-specific know-how and have substantial experience working together; hence, they are less likely to misread blueprints or misinterpret information (Nishiguchi 1994; Clark 1989; Clark and Fujimoto 1991; Westney and Sakakibara 1986; Stalk and Hout 1990; Helper 1991).

The ability to develop new products rapidly is an important source of competitive advantages in many firms, not only Japanese ones. We contend that competitive advantages from supplier networks could be particularly important in high-technology firms that compete by rapid introduction of differentiating, high value-added products.

In studying innovations in *firms*[35] rather than industries, we encountered the problem that only some firms within each "high-tech SIC code" may be high tech. Thus, we asked establishments in our sample (374 establishments) what percentage of their labor force was represented by engineers and scientists. Using this information, we classified each firm *within* a high-tech SIC sector: those in which at least 6 percent of their total employees are engineers and scientists we called *high-tech firms* (135 establishments), and those with a proportion of engineers and scientists less than 6 percent we called *non-high-tech firms* (128 establishments). In doing this, we follow Markusen et al. (1986), who found that the national average of the proportion of engineers, engineering technicians, computer scientists, life scientists, and mathematicians to total workforce for all industries was 5.82 percent.

We hypothesized that a high-technology firm, in the process of developing new products and processes, establishes relationships with three types of firms: suppliers, customers, and competitors.[36] We adopted Helper's (1987, 1989) definition of "voice relationships" as a proxy for network (versus arm's length) relationships and assumed that three aspects of network systems can affect firms' innovations: (1) frequency of technical (engineering and scientific, as opposed to sales and ordering) information exchange, (2) length of contracts, and (3) flexibility of contracts.

On the positive side, results from our logit models indicate that high-technology firms in Texas are significantly more likely to perceive the relationship with *customers* as important in developing new products (proxy for product innovations) or reducing manufacturing and development cycles (proxy for process innovations) if the degree of networking with customers is high. A high degree of networking means firms and customers exchange knowledge (scientific and engineering information) daily or weekly and have flexible, long-term contracts. However, these networks seem to be *asymmetric*—that is, in developing new products and processes, high-

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[35] We used interchangeably the terms firm and establishment although as we acknowledged previously the economic theory distinguishes between them.

[36] We found that relationships with other firms (competitors) were not important for firms in the innovation performance of firms in our sample. Similar results were found in a pilot study on the U.S. high technology industry (NSF 1996).

tech firms *provide* technical information more frequently than they *receive* it (see Figure 4 on page 47).

On the negative side, firms' relationships with *suppliers* in developing new products and processes is more characteristic of arm's length relationships. High-tech firms and suppliers exchange little technical information. Also, these firms prefer short-term contracts with suppliers when developing new products and processes. Only the importance of the flexibility of the contract in innovations emulates a component of network relationships (see figure 5 on page 51). The little support for *supplier* networks as an explanatory variable in the innovative performance of high-technology firms in Texas aligns with Helper's (1989) findings on the relationship between U.S. automakers and their suppliers. In that study, automakers showed more of a desire to transfer inventory costs to suppliers than to establish partner relationships. Our results, however, seem surprising given the abundance of examples of the positive effects for innovations of close relationships with suppliers, not only for Japanese firms but also for high-technology firms in Silicon Valley.

According to Saxenian (1994), computer firms in Silicon Valley redefined relations with their most important suppliers during the 1980s. Recognizing that their success was inextricably tied to that of their suppliers, these firms began treating the suppliers as partners in a joint process of designing, developing, and manufacturing innovative systems. These collaborative relationships allowed both customer and supplier to become more specialized and technologically advanced. A network of long-term partnerships with specialist suppliers also gave computer companies a formidable competitive advantage that was difficult for competitors to replicate.

Supplier networks, then, promote technological advance. In Saxenian's (1994) view, collaboration in a network system encourages joint problem solving between system firms and their suppliers. In the example of Silicon Valley, firms learned to respond collectively to fast-changing markets and technology.

Do suppliers tend to locate in the same metropolitan area as the high-technology firm? Saxenian (1994) reports that Silicon Valley-based computer manufacturers often preferred local suppliers, particularly for technologically complex or customized parts. This preference for geographical proximity was not reducible to costs considerations. She argues (p. 157) that "most saw the advantages of timely delivery but also recognized that it was difficult to create over long distances the trust and teamwork needed for collaborative supplier relations."

However, the Silicon Valley locational patterns seem to differ from those of the high-technology industry in Texas, where most of the main suppliers tend to be scattered rather than concentrated in the same metropolitan area as the high-technology firms. For instance, 71 percent of high-technology firms in our sample indicated that their main suppliers were dispersed rather than centralized in their same metropolitan area. Moreover, when asked to rank from 1 to 5 the importance of several factors in the performance of their firms (with 1 being not important and 5 being very important), the group of high-tech firms in our sample assigned a relatively low average valuation (2.60) to their individual metropolitan areas as an important locus for the majority of their sales/purchases. Thus, although some Texas high-technology firms may be located in the same city as their suppliers, most are global firms with their most important suppliers (and customers) dispersed around the world.

In sum, high-tech firms' relationships with suppliers and customers can be an important source of knowledge for innovations, but these suppliers and customers are scattered all around, not concentrated in one metropolitan area. We questioned the firms in our survey regarding other possible sources of *local* knowledge relevant for innovations in order to understand the reasons why high tech-firms agglomerate.

How Can a Region Attract High- Instead of Non-High-Technology Firms?

The positive relationship between *local* knowledge spillovers and innovations is based on the assumption that firms cannot appropriate all the knowledge they generate. Part of the knowledge "spills over" and is appropriated by other firms that do not pay for it. The importance of knowledge spillovers for innovations, however, extends beyond the relationship between "legal agents" (i.e., those between firms) to include relationships established between educated *people* who just happen to live in the same city. In this context, an urban area can be an important locus for communication between a firm's skilled labor and the skilled labor in local universities, technical institutes, and other local high-tech firms—even when a high-tech firm does not have a formal agreement with any of these legal agents.

In fact, most studies of the high-technology industry maintain that the innovative capacity of high-technology firms depends on knowledge externalities emerging from the informal *local* relationships of their executives and engineers. Thus, the studies identify local knowledge spillovers as an important component of this industry where growth has not taken the form of large physical plants, but instead has developed through the accumulation of *local* intellectual capital. As Angel (1995) suggests, much technological knowledge in the high-technology industry is tacit, embedded in the skills and experiences of workers and local institutions and not easily transferable across national and regional boundaries.

We recognize that while it is not possible to directly measure the extent to which knowledge externalities exist, it is possible to identify main sources of knowledge externalities for firms. The crucial assumption we make here is that knowledge spillovers are more important and embodied, at least to some degree, in skilled labor, in particular, engineers, scientists, and technicians. Firms can obtain skilled labor essentially from three main sources: universities, technical institutes, and other firms (beside suppliers and customers). Thus, we question the importance of these local sources of technical information in the performance of high-technology firms.

In our sample, the average response evaluation for local universities as a source of engineers and scientists was 2.36, indicating that most high-technology firms give little valuation to the availability of engineers and scientists from local universities as a main determinant of their performance. Firms do not limit themselves to local universities when hiring engineers and scientists; on the contrary, they hire most of their engineers and scientists from the most prestigious universities in the United States. Interviewees told us that they look for expertise wherever it is available.[37] The role that universities can play in the innovative performance of local firms is more complex. In this regard, Saxenian (1994) maintains that differences in the relationships of MIT and Stanford with their respective local firms explain the differences in the industrial systems in Silicon Valley and Route 128. MIT's relations with established large corporations reinforced a tendency toward arm's length relations and excluded most small and medium-sized companies.[38] Stanford, in contrast, offered an important advantage to small companies that sought to attract top talent but were unable to provide the continuing education and training needed in a fast-changing technological environment.[39] Future research should focus on the kinds of relationships that Texas universities should maintain with high-technology firms and on which kinds are more conducive to innovations.

Other local firms can also be an important source of engineers and scientists. However, the high-technology firms in our sample gave little valuation to this factor (average of 2.58) in their performance. Firms do not limit themselves to hiring engineers and scientists from the locality; on the contrary, most are hired from other high-technology regions. In fact, perhaps the most significant job difference between Silicon Valley and Austin is the lack of job-shifting by engineers and middle managers in Austin (Solid State Technology 1994). Angel (1995), for instance, notes that semiconductor firms in Silicon Valley fill the majority of job vacancies from within the local labor market, drawing on the large pool of *specialized* labor skills within the region. In his view, one consequence of this interfirm mobility is that firms in the region have the opportunity to recruit workers with experience from the local labor market, thereby avoiding the need to develop requisite skills and experience in-house (e.g., through internal training programs).

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[37] Similar results were found in a recent study based on interviews with 24 high tech firms in Austin (Oden 1997).

[38] Over time, some of the Route 128 region's *large* firms themselves began to offer employees training and education. This posed an obvious problem for small and medium-sized firms, which could not afford the cost of training programs.

[39] It opened its classrooms to local companies through the Honors Cooperative Program and encouraged engineers at electronics companies to enroll in graduate courses directly or through a specialized televised instructional network that brought Stanford courses into company classrooms. The Stanford Industrial Affiliates Program facilitates direct interaction between the university and firms of all sizes.

Unlike the situation for engineers and scientists, technical personnel are hired mainly locally. In fact, the average valuation for the local area as a source of technical personnel was 3.17 for high-technology firms. This local factor received the second highest valuation in the performance of high-tech firms in our sample, after quality of life (3.69). Technicians tend to be less mobile, and the fixed costs of recruiting technicians outside the local area will be a large percentage of the wages paid to them.[40] Shortage of skilled labor is often cited as an important constraint on future growth in the high-technology sector; however, because of the difficulty of moving technicians, a tight local labor market usually means a short supply of technicians. Samsung in Austin, for instance, is offering cash incentives to recruit mostly technicians and operators (Oden 1997).

Local knowledge can also come from a direct relationship with scientists and professors in a local university. However, its importance was given only a 2.58 average score, indicating that this kind of local knowledge is not a significant determinant in the performance of high-technology firms. This is consistent with other findings in the literature. For instance, Jaffe (1989) finds little support for the hypothesis that biotechnology firms tend to rely more on local scientists. The lack of geographical barriers in the relationship between R&D and the performance of high-tech firms is not surprising considering that large funding for industry-relevant research comes from the federal government and benefits the U.S. high-tech industry, not just the high-technology firms located in that city. For instance, the impact of research conducted at SEMATECH and MCI transcends the geographical boundaries of their Austin locations to benefit the U.S. semiconductor industry against Japanese competition (see Gibson and Rogers 1994 for a good account of these institutions).

Krugman (1991) poses an important question: Do high-technology firms concentrate because most of the knowledge relevant for their innovations is obtained from the local area, or do they locate in a city for the same reasons that non-high-tech firms locate there? Our findings that most sources of knowledge for innovations in Texas high-technology firms are obtained from

[40] Similar results were found in a recent study based on interviews with 24 high tech firms in Austin (Oden 1997).

outside the metropolitan area (only technicians are hired mainly from the local area) indicates that local knowledge spillovers are not the raison d'être for high-technology firms to agglomerate. This evidence supports Krugman's (1991) hypothesis that innovative firms may agglomerate for other reasons, such as the quality of life or availability of major inputs, which are also the reasons why non-high-tech firms agglomerate.

We argue that the reasons why high-technology firms agglomerate are economies of specialization associated with the size of the economic activities within a city. In essence, a large city becomes a magnet for skilled labor. The concentration of a large number of high-tech firms becomes an indirect source of attraction for engineers and scientists who expect to hop from one high-tech firm to another. The presence of a large university also acts as a magnet for attracting skilled labor. Continuing higher education in a major university is an important factor in an engineer's decision to move to a high tech region. A large university also attracts large research projects—such as SEMATECH and MCI—that serve to enhance the capacity of the city to draw skilled labor. Thus, agglomeration economies play a significant role in facilitating the migration of skilled labor to the city.

However, we disagree with Krugman's (1991) view that high- and non-high-tech firms may locate for similar reasons. Results from our survey indicate that high-tech firms seem to depend more on technical personnel; non-high-tech firms, on the local market. Thus, while the presence of good technical institutions may be a decisive factor in a high-tech firm's decision to locate in a specific city, a large pool of customers and suppliers may be more important to a non-high-tech firm. Moreover, although factors such as quality of life and good infrastructure consistently list among the important determinants in high-tech firm location decisions, we find that these factors are equally important for non-high-tech firms. If policymakers want to attract only high-tech firms, they should focus their efforts on providing good technical personnel and developing economies of scale by attracting other high-tech firms and supporting a large university.

Not all high-tech firms conduct research and development that leads to innovations. Some only assemble the products resulting from R&D conducted at headquarters located in a different state. Because the economic development benefits perceived from high-technology firms are mainly associated with the implicit assumption that they are highly innovative activities, we asked which "urban" attributes are exclusive to *innovative* high-technology firms.

How Can a City Attract Innovative High-Technology Firms?

Saxenian (1994) believes that firms' organizational structures and their relationships to their respective regions help explain the differences in their innovative performance. She attributes the innovative success of high-tech firms in Silicon Valley to their regional network systems that are based on a surprising degree of cooperation—almost Japanese in its closeness—among companies. *Local* networks are widely recognized as an important factor not only in the innovative success of a firm (Porter 1990; Audretsch and Feldman 1996), but also in their ability to penetrate foreign markets, independently of their size.[41]

In contrast, there is little research on the importance of *external networks* in the innovation performance of firms. Our study represents a contribution in this direction. We imply from this analysis that external linkages of skilled labor play a key role in expanding access to knowledge, and therefore, these linkages have a positive effect on firms' innovations. We find significant evidence of the importance of *external* knowledge networks in the innovative performance of high-tech firms:

(a) As already indicated, most high-technology firms in our sample give little valuation to their relationship with suppliers in their product/process innovations. However, those high-technology firms that recognize the significance of their relationship with suppliers (which are mainly scattered all around) are developing new products and

[41] Much of this work has built upon the experience of "the Third Italy" and the role that formal and informal production networks have played in that region's growth. Similar industrial clusters have been identified in other parts of Europe—for example, Germany's Baden-Wurttemberg region, Denmark's Jutland region, and Mediterranean France.

processes faster than their competitors, as anticipated by the theory and empirical studies on Silicon Valley.

(b) Texas high-technology firms that maximize access to external (non-local) sources of knowledge by locating in cities that provide frequent flights for their employees are more likely to develop new products faster than their competitors. Accessibility variables also proved to be very important in Markusen et al.'s (1986) pioneering study of the U.S. high-technology industry, both in terms of internal mobility (freeway density) and, more important, in terms of airport access. In fact, they suggest that the business travel aspect of airports may be more important than air cargo services in attracting high-tech companies.

(c) Texas high-technology firms that maximize access to external (non-local) sources of knowledge by hiring some technical personnel from outside the city are also more likely to develop new products faster than the competition.

Although we agree that independent firm-based industrial systems respond more slowly than network-based systems to changing markets and technologies, our evidence does not support the view that the most strategic relationships are essentially local. There seem to be *complementarities* between local and external relationships, and, in fact, both are strategic in the development of new products and processes. A firm learns from other firms, which explains why it establishes networking relationships with other firms (including its most important customers and suppliers). These relationships, however, are not constrained by geographical boundaries. As firms expand their knowledge based on the process of developing more technologically sophisticated products, the demand for interaction of all sorts (internal and external) should increase. At the same time, the role of cities as centers of *both* internal and external interaction should also expand.

The view that gives "exclusive" importance to *local* knowledge spillovers in innovations is based on the argument that relatively close proximity of companies and skilled individuals makes association not only easier (Saxenian 1994), but also less costly (Krugman 1991). Spatial proximity facilitates occupational mobility (individuals move both within and between sectors) and informal exchange of information. In particular, when knowledge (as opposed to information) is costly to transfer, spatial proximity become a necessary condition for innovations to take place (Audretsch and Feldman 1996). If knowledge is expensive to transfer across long distances, one would assume that innovative firms' most strategic relationships—in particular those with potential sources of knowledge, such as main suppliers/customers, universities, and technical institutions—would be mainly *local*. Our results indicate that knowledge may be more expensive to transfer than information, but it may also provide companies with more *benefits* than information, especially in terms of the positive effects that it has on innovations. In this context, companies may have an incentive to look for knowledge outside the city.

Summary of the Main Findings

- Although factors such as quality of life and good infrastructure have been consistently found to be important determinants in the location of high-tech firms, we find that these factors are equally important for non-high-tech firms. If policymakers want to attract only high-tech firms, they should focus their efforts on providing good technical personnel, attracting other high-tech firms, and supporting a large university. These last two factors are important in attracting skilled labor.

- If the objective is to attract high-tech firms active in innovations, policymakers should focus on providing not only the right local technical personnel, but also the infrastructure that allows frequent communication with other areas high in sources of knowledge. Such infrastructure is necessary because knowledge is widely distributed, and therefore the locus of innovations is found in both local and external relationships.

- A key issue in the growth of R&D in Texas is the quality, location, and convenience of commercial airline service that facilitates frequent communication between local high-technology firms and their suppliers, their customers, and universities that specialize in their particular needs, all of which are mainly located outside the area.

- Also important to the growth of R&D in Texas is the availability of technical personnel locally or information on the availability of technical personnel outside the region.

- Organizational arrangements, such as network systems, that provide access to knowledge quickly and reliably produce competitive advantages in the innovation performance of high-technology firms. These competitive advantages, however, are not affected by the locational patterns of network firms.[42]

- Competitive advantages in terms of firms' innovation performance are associated with networking relationships with both customers and suppliers. Our results indicate that most high-tech firms in Texas overlook an important strategy in developing new products faster than competitors: establishing networking relationships with suppliers.

- Local universities can maintain cooperative relationships with local high-technology firms by (1) creating programs at the university that facilitate direct interaction with local firms and (2) getting high-tech firms to commit to financing and supporting these programs. One important step in this direction would be the creation of a *high technology program* at the University of Texas at Austin. The program would emulate MIT's Automobile Vehicle Program, but would focus on the high-technology industry in Texas. It would be a joint initiative between the College of Business Administration and the College of Engineering to help Texas high-technology firms (in particular, small and medium-sized ones) develop specialized supplier networks as a source of innovative advantage. Funding for the program would come from Texas high-technology firms and perhaps the Higher Education Coordinating Board.

[42] It is important to indicate that even the assumed spatial proximity that characterized Japanese automobile firms in Japan and the United States has been questioned by the dispersed geographical patterns shown by Japanese automobile firms in Europe (Saddler 1992; Echeverri-Carroll 1994).

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Appendix A

Definition of High Technology Industries
(Table 1)

Markusen, Hall, and Glasmeier (1986) list 100 industries as high tech, based on the percentage of engineers, engineering technicians, computer scientists, life scientists, and mathematicians in the industry labor force. The national average for all industries is 5.82%. Industries are defined as high tech if the industry average exceeds 5.82%. Based on this classification scheme, 30 sectors (3-digit SIC) are classified as high tech. The data used to create this definition is disaggregated to the 3-digit level only. Within these sectors are 100 4-digit industries, as listed below. This is the database used by Markusen, Hall, and Glasmeier. NEC means "not elsewhere classified."

Table 1. 100 4-digit SIC codes defined as high-technology manufacturing industries.[43]

Industry name (1972 SIC codes)	1972 SIC	1987 SIC
alkalies & chlorine	2812	2812
industrial gases	2813	2813
inorganic pigments	2816	2816
industrial inorganic chemicals, NEC	2819	2819
plastic materials, synthetic resins	2821	2821
synthetic rubber	2822	2822
cellulosic man-made fibers	2823	2823
synthetic organic fibers, except cellulose	2824	2824
biological products	2831	2835, 2836[44]
medical, chemical, botanical products	2833	2833
pharmaceutical preparations	2834	2834
soap, other detergents	2841	2841
special cleaning, polishing preparations	2842	2842
surface active finishing agents	2843	2843
perfumes, cosmetics, toilet preparations	2844	2844
paints, varnishes, lacquers, enamels	2851	2851
gum, wood chemicals	2861	2861
cyclic crudes, intermediates, dyes	2865	2865
industrial organic chemicals, NEC	2869	2869
nitrogenous fertilizers	2873	2873
phosphatic fertilizers	2874	2874
fertilizers, mixing only	2875	2875
pesticides, agricultural chemicals, NEC	2879	2879
adhesives, sealants	2891	2891

[43] In converting 1972 SIC codes to 1987 SIC codes, in cases where parts of one 1972 SIC code become included in more than one 1987 industry group, we only counted it once.

[44] 1972 SIC code 2831 was split into 1987 SIC codes 2835 (in vitro and in vivo diagnostic substances) and 2836 (biological products, except diagnostic substances).

explosives	2892	2892
printing ink	2893	2893
carbon black	2895	2895
chemicals, chemical preparations, NEC	2899	2899
petroleum refining	2911	2911
reclaimed rubber	3031	3069[45]
small arms ammunition	3482	3482
ammunition, except small arms, NEC	3483	3483
small arms	3484	3484
ordnance, accessories, NEC	3489	3489
steam, gas, hydraulic turbines	3511	3511
internal combustion engines, NEC	3519	3519
construction machine equipment	3531	3531
mining machinery equipment	3532	3532
oilfield machinery equipment	3533	3533
elevators, moving stairways	3534	3534
conveyors, conveying equipment	3535	3535
hoists, industrial cranes, monorail systems	3536	3536
industrial trucks, tractors, trailers, stackers	3537	3537
machine tools, metal cutting types	3541	3541
machine tools, metal forming types	3542	3542
specialty dies, die sets, jig fixtures, industry molds	3544	3544
machine tool accessories, measuring devices	3545	3545
power-driven hand tools	3546	3546
rolling mill machinery equipment	3547	3547, 3548[46]
metalworking machinery, NEC	3549	3549
pumps, pumping equipment	3561	3561
ball, roller bearings	3562	3562
air, gas compressors	3563	3563
blowers, exhaust, ventilation fans	3564	3564
industrial patterns	3565	3543
speed changers, industrial high drives, gears	3566	3566
industrial process furnaces, ovens	3567	3567
mechanical power transmission equipment, NEC	3568	3568
general industrial machinery equipment, NEC	3569	3565, 3569, 3594[47]

[45] 1972 SIC code 3031 (reclaimed rubber) became 1987 SIC code 3069 (fabricated rubber products, NEC)

[46] Additional 1987 SIC code: 3548 (electric and gas welding and soldering equipment).

[47] 1972 SIC code 3569 was split into 1987 SIC codes 3594 (fluid power pumps and motors), 3565 (packaging machinery), and 3569 (general industrial machinery, NEC).

electronic computing equipment	3573	3571, 3572, 3575, 3577, 3695[48]
calculating acctg. mach., except electrical computer equip.	3574	3578
scales, balances, except laboratory	3576	3596
office machinery, NEC	3579	3579
power, distribution special transformers	3612	3612
switch gear, switchboard apparatus	3613	3613
motors, generators	3621	3621
industrial controls	3622	3625
welding apparatus, electric	3623	3548
carbon, graphite products	3624	3624
electrical industrial apparatus, NEC	3629	3629
radio, TV receiving sets, except communication types	3651	3651[49]
phono records, pre-recorded magnetic tape	3652	3652
telephone, telegraph apparatus	3661	3575, 3661[50]
radio, TV transmitting, signal, detection equipment	3662	3661, 3663, 3669, 3699, 3812, 3829[51]
cathode ray tubes, NEC	3671, 3672, 3673	3671[52]
semiconductors, related devices	3674	3674
electronic capacitators	3675	3675
resistors for electronic applications	3676	3676
resistors, electric apparatus	3677	3677
connectors, electronic applications	3678	3678
electronic components, NEC	3679	3679
aircraft	3721	3721
aircraft engines, parts	3724	3724
aircraft parts, auxiliary equipment, NEC	3728	3728
railroad equipment	3743	3743

[48] 1972 SIC code 3573 was split into 1987 SIC codes 3571 (electronic computers), 3572 (computer storage devices), *part of* 3575 (computer terminals), 3577 (computer peripheral equipment, NEC), and 3695 (magnetic and optical recording media).

[49] SIC code 3651 was renamed in 1987: household audio and video equipment.

[50] 1972 SIC code 3661 became *part of* 1987 SIC 3575 (computer terminals) and *part of* SIC 3661 (telephone and telegraph apparatus).

[51] 1972 SIC code 3662 was split into the following 1987 SIC codes: *part of* 3661 (telephone and telegraph apparatus), 3663 (radio and TV communications equipment), 3669 (communications equipment, NEC), *part of* 3699 (electrical equipment and supplies, NEC), *part of* 3812 (search and navigation equipment), and *part of* 3829 (measuring and controlling devices, NEC).

[52] 1972 SIC codes 3671 (electron tubes, receiving type), 3672 (cathode ray tubes, NEC), and 3673 (electron tubes, transmitting) became 1987 SIC code 3671 (electron tubes).

guided missiles, space vehicles	3761	3761
guided missiles, space vehicles, propulsion units	3764	3764
guided missiles, space vehicles, parts, NEC	3769	3769
tanks, tank components	3795	3795
engineering, laboratory, scientific, research instruments	3811	3812, 3821, 3826, 3829[53]
indus. controls for communic. and environmental applic.	3822	3822
industrial instruments for measurement and display	3823	3823
fluid meters, counting devices	3824	3824
instruments, measuring, testing, electrical, electrical signals	3825	3825
measuring, controlling devices, NEC	3829	3829
optical instruments, lenses	3832	3827[54]
surgical, medical instruments apparatus	3841	3841
orthopedic, prosthetic, surgical applications	3842	3842
dental equipment, supplies	3843	3843[55]
photographic equipment, supplies	3861	3861

[53] 1972 SIC code 3811 was split into the following 1987 SIC codes: *part of* 3812 (search and navigation equipment), 3821 (laboratory apparatus and furniture), *part of* 3826 (analytical instruments), *part of* 3829 (measuring and controlling devices, NEC).

[54] 1972 SIC 3832 was split into the following 1987 SIC codes: *part of* 3826 (analytical instruments), SIC 3827 (optical instruments and lenses),and *part of* 3829 (measuring and controlling devices, NEC).

[55] We also included 1987 SIC codes 3844 (X-ray apparatus and tubes and related irradiation apparatus) and 3845 (electromedical and electrotherapeutic apparatus).

Appendix B

Notes on Total Employment Data

County Business Patterns (CBP) data is a mid-March snapshot of full and part-time employment from payrolls. It does not include self-employed proprietors or much of the government sector and therefore cannot be used to determine total employment.

Of the regions we selected, all correspond to MSA divisions except Southern California/Los Angeles and Route 128. Therefore, county level data is required to determine total employment coinciding with our defined regions. It is also necessary that the data be collected on an annual basis so that information from 1989 and 1993, specifically, can be extracted.

The Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS) were considered for the current task. There is no reason to look for smaller or more obscure sources for statistics as comprehensive as total employment by county for the entire United States. We have to look at well known sources. BLS is organized by state only, not by MSA, so it will not serve our purposes. BEA is organized annually, by county, MSA, and state (but not by SIC code); it distinguishes proprietors from employees, government from non-government, and farm from non-farm employment. BEA statistics are employment figures averaged over a twelve-month period.

We concluded that the best approach to calculating total (non-farm) employment is to use the sum of CBP county totals with BEA county government employment totals and then aggregate these to the regions we specified. Both sources look at payroll information, but BEA and CBP are not wholly compatible for the following reasons: (1) BEA is an annual average and CBP is a mid-March snapshot, and (2) CBP does not include unsalaried proprietors and BEA does; this would not affect the government sector but does affect employment totals. Some spot calculations by county and MSA comparing CBP and BEA total employment figures show a consistent discrepancy on the order of 10 percent between the two sources. But calculations comparing the ratio of CBP manufacturing to CBP total employment plus BEA government employment with the ratio of BEA manufacturing employment to BEA total employment are roughly comparable (+/- 1%). We concluded that given the CBP data already in hand, the best approach is to calculate total employment as the sum of CBP total employment with BEA government employment.

These results from our model are complemented by other information we got from non-high-tech firms in our sample. In fact, of 170 high-tech firms that responded to the question of whether their main customers were located in the same metropolitan area as themselves or scattered all around, 80 percent (137 firms) responded that their most important customers were located all around. These results are consistent with what was said by the managers we interviewed: that in relatively few instances are the most important customers located in the same metropolitan area as the partner firm. For instance, only 60 percent (97 firms) of the non-high-tech firms (versus 80 percent of the high-tech firms) that responded to the question of whether their main customers where located in the same metropolitan area as themselves or scattered all around say that their most important customers were scattered all around. Non-high-tech firms also tend to have suppliers scattered all around. Of 161 non-high-tech firms that responded to the question of whether their main suppliers were located in the same metropolitan area as themselves or scattered all around, 68 percent (110 firms) responded that their main suppliers were scattered all around. In fact, of 168 high-tech firms that responded to the question of whether their main suppliers were located in the same metropolitan area as themselves or scattered all around, 71 percent (119 firms) responded that their most important suppliers were located all around.

Appendix C

Tables 3–7

Table 3. Total employment by region for top five high-technology manufacturing SIC codes.

Area	SIC code	Industry name	Employment *1989*	*1993*	Change
MASSACHUSETTS					
Route 128					
	3679*	Electronic Components	6,938	9,267	2,329
	3674	Semiconductors	9,134	8,589	-545
	3841*	Surgical and Medical Instruments	5,270	7,355	2,085
	3724	Aircraft Engines and Engine Parts	9,250	6,531	-2,719
	3661	Telephone and Telegraph Equipment	8,569	5,981	-2,588
	3571†	Electronic Computers	20,014	5,235	-14,779
	3761†	Missiles and Space Vehicles	7,500	3,750	-3,750
CALIFORNIA					
Southern California					
	3721	Aircraft	79,390	50,601	-28,789
	3728	Aircraft Parts	51,718	37,542	-14,176
	3761	Missiles and Space Vehicles	67,175	34,089	-33,086
	3679	Electronic Components	19,786	18,967	-819
	3674*	Semiconductors	14,497	12,842	-1,655
	3571†	Electronic Computers	14,555	6,005	-8,550
Silicon Valley					
	3674	Semiconductors	41,353	34,291	-7,062
	3571	Electronic Computers	31,703	22,206	-9,497
	3761	Missiles and Space Vehicles	37,500	17,500	-20,000
	3679	Electronic Components	17,231	17,337	106
	3661*	Telephone and Telegraph Equipment	7,415	9,945	2,530
	3671†	Electron Tubes	9,555	1,507	-8,048
NORTH CAROLINA					
Research Triangle Park					
	3571*	Electronic Computers	195	18,250	18,055
	3661	Telephone and Telegraph Equipment	7,500	5,234	-2,266
	2834*	Pharmaceutical Preparations	1,135	1,935	800
	3841*	Surgical and Medical Instruments	870	1,870	1,000
	3625	Relays and Industrial Controls	1,560	1,750	190
	3825†	Instruments for Measuring Electricity	1,945	1,135	-810
	3629†	Electrical Industrial Apparatus	1,750	375	-1,375
	3679†	Electronic Components	1,403	10	-1,393

TEXAS

	Austin			
3679	Electronic Components	7,735	12,270	4,535
3674	Semiconductors	7,675	9,531	1,856
2834	Pharmaceutical Preparations	1,925	1,925	0
3571	Electronic Computers	2,841	1,760	-1,081
3842*	Orthopedic and Surgical Supplies	750	1,750	1,000
3728†	Aircraft Parts	1,750	175	-1,575
	Dallas			
3728	Aircraft Parts	17,350	7,640	-9,710
3674	Semiconductors	9,845	9,935	90
3661*	Telephone and Telegraph Equipment	2,125	6,310	4,185
3679	Electronic Components	4,262	4,204	-58
3721	Aircraft	3,942	4,500	558
3761†	Missiles and Space Vehicles	3,750	0	-3,750
	Fort Worth			
3721	Aircraft	37,510	17,510	-20,000
3728	Aircraft Parts	1,043	7,114	6,071
2834	Pharmaceutical Preparations	1,810	3,750	1,940
3674*	Semiconductors	750	1,750	1,000
3579	Office Machines	750	1,750	1,000
3069†	Fabricated Rubber	1,760	983	-777
3661†	Telephone and Telegraph Equipment	1,750	750	-1,000
	Houston			
3533	Oil and Gas Field Mach. and Equipment	10,928	8,338	-2,590
2869	Industrial Organic Chemicals	7,995	10,012	2,017
2821	Plastics Materials	4,890	6,483	1,593
3571	Electronic Computers	7,510	2,684	-4,826
2879†	Pesticides and Agricultural Chemicals	1,812	1,647	-165
3511*	Steam, Gas and Turbine Generators	1,750	3,750	2,000
	San Antonio			
3721	Aircraft	1,750	1,750	0
3674	Semiconductors	750	750	0
3661*	Telephone and Telegraph Equipment	235	435	200
3569	General Industrial Machinery	375	375	0
2834	Pharmaceutical Preparations	435	375	-60
3724*	Aircraft Engines	175	375	200
3841†	Surgical and Medical Instruments	375	279	-96
3571†	Electronic Computers	375	175	-200
3625†	Relays and Industrial Controls	375	175	-200

*Top five in 1993 only. †Top five in 1989 only.
Source: Data extracted from County Business Patterns CD ROM records 1989-1990 and 1992-1993.

Table 4. Total employment by region for top five high-technology service SIC codes.

Area	SIC code	Industry name	Employment 1989	Employment 1993	Change
MASSACHUSETTS					
		Route 128			
	8711	Engineering Services	19,791	16,891	-2,900
	7372	Prepackaged Software	8,422	13,822	5,400
	7371	Computer Programming Services	6,981	10,564	3,583
	8731	Commercial Physical and Biological Research	15,362	9,878	-5,484
	7374*	Computer Processing and Data Preparation Services	5,029	8,874	3,845
	8721†	Accounting, Auditing and Bookkeeping Services	6,671	4,934	-1,737
CALIFORNIA					
		Southern California			
	8721	Accounting, Auditing and Bookkeeping Services	60,885	63,992	3,107
	8711	Engineering Services	52,330	51,356	-974
	8741	Management Services	29,458	36,729	7,271
	7371	Computer Programming Services	20,136	19,160	-976
	8742	Management Consulting Services	19,903	17,040	-2,863
		Silicon Valley			
	7372*	Prepackaged Software	8,037	24,715	16,678
	8711	Engineering Services	26,826	22,793	-4,033
	7371	Computer Programming Services	13,861	15,215	1,354
	8721	Accounting, Auditing and Bookkeeping Services	14,193	12,727	-1,466
	8731	Commercial Physical and Biological Research	10,512	10,568	56
	8742†	Management Consulting Services	8,847	8,631	-216
NORTH CAROLINA					
		Research Triangle Park			
	8711	Engineering Services	2,578	3,218	640
	8731	Commercial Physical and Biological Research	2,091	2,419	328
	7373*	Computer Integrated Systems Design	620	2,306	1,686
	7371*	Computer Programming Services	1,198	2,283	1,085
	8721	Accounting, Auditing and Bookkeeping Services	1,655	1,990	335
	7372†	Prepackaged Software	1,907	1,605	-302
	8741†	Management Services	1,230	1,647	417

TEXAS

	Austin			
8711	Engineering Services	5,211	5,493	282
8741	Management Services	1,207	2,302	1,095
7373*	Computer Integrated Systems Design	166	2,118	1,952
7371*	Computer Programming Services	600	1,562	962
8721	Accounting, Auditing and Bookkeeping Services	1,326	1,441	115
8731†	Commercial Physical and Biological Research	1,562	1,089	-473
8742†	Management Consulting Services	1,137	2,302	1,165
	Dallas			
7374	Computer Processing and Data Prep. Services	14,708	16,075	1,367
8741	Management Services	7,564	12,332	4,768
8721	Accounting, Auditing and Bookkeeping Services	8,490	9,234	744
8711	Engineering Services	6,879	5,985	-894
8742*	Management Consulting Services	3,740	5,809	2,069
7371†	Computer Programming Services	3,803	5,332	1,529
	Fort Worth			
8721	Accounting, Auditing and Bookkeeping Services	2,949	2,063	-886
8711	Engineering Services	1,796	1,932	136
8741	Management Services	3,025	1,825	-1,200
8742	Management Consulting Services	976	1,184	208
7375*	Information Retrieval Services	10	750	740
7371†	Computer Programming Services	604	365	-239
	Houston			
8711	Engineering Services	21,376	32,475	11,099
8721	Accounting, Auditing and Bookkeeping Services	8,265	10,359	2,094
8741	Management Services	6,983	8,763	1,780
7371*	Computer Programming Services	3,390	7,292	3,902
7374	Computer Processing and Data Prep. Services	4,143	3,879	-264
8742†	Management Consulting Services	4,800	3,499	-1,301
	San Antonio			
8731	Commercial Physical and Biological Research	1,810	3,047	1,237
8721	Accounting, Auditing and Bookkeeping Services	1,975	2,830	855
8711	Engineering Services	1,312	2,189	877
8741	Management Services	1,041	1,515	474
8742*	Management Consulting Services	450	1,295	845
7374†	Computer Processing and Data Preparation Services	696	861	165

*Top five in 1993 only. †Top five in 1989 only.
Source: Data extracted from County Business Patterns CD ROM records 1989-1990 and 1992-1993.

Table 5. Main high-technology manufacturing industries in five major Texas metropolitan areas.

Includes top five high-tech 4-digit SIC codes by volume of employment and top five by number of firms.

Austin			
3544	Special Dies and Tools, Die Sets, Jigs and Fixtures, and Industrial Molds	3571	Electronic Computers
3672	Printed Circuit Boards	2834	Pharmaceutical Preparations
3679	Electronic Components, NEC	3674	Semiconductors and Related Devices
3823	Industrial Instruments for Measurement and Related Products	3842	Orthopedic, Prosthetic, and Surgical Appliances and Supplies
Fort Worth			
3728	Aircraft Parts and Auxiliary Equipment, NEC	3544	Special Dies and Tools, Die Sets, Jigs and Fixtures, and Industrial Molds
3533	Oil and Gas Field Machinery, Equip.	2899	Chemicals and Chemical Preps., NEC
3535	Conveyors and Conveying Equipment	3721	Aircraft
3679	Electronic Components, NEC	2834	Pharmaceutical Preparations
3069	Fabricated Rubber Products, NEC	3674	Semiconductors and Related Devices
Dallas			
3544	Special Dies and Tools, Die Sets, Jigs and Fixtures, and Industrial Molds	3728	Aircraft Parts and Auxiliary Equipment, NEC
3679	Electronic Components, NEC	3674	Semiconductors and Related Devices
3721	Aircraft	3661	Telephone and Telegraph Apparatus
3823	Industrial Instruments for Measurement and Related Products	2842	Specialty Cleaning, Polishing, and Sanitation Preparations
2899	Chemicals and Chemical Preps., NEC		
Houston			
3533	Oil and Gas Field Machinery and Equipment	3511	Steam, Gas, and Hydraulic Turbines, and Turbine Generator Set Units
3823	Industrial Instruments for Measurement and Related Products	2821	Plastics Materials, Synthetic Resins, and Nonvulcanizable Elastomers
2899	Chemicals and Chemical Preps., NEC	2869	Industrial Organic Chemicals, NEC
3561	Pumps and Pumping Equipment	3571	Electronic Computers
3569	Gen. Indus. Machinery, Equip., NEC		
San Antonio			
3728	Aircraft Parts and Auxiliary Equipment, NEC	3537	Industrial Trucks, Tractors, Trailers, and Stackers
3544	Special Dies and Tools, Die Sets, Jigs and Fixtures, and Industrial Molds	2842	Specialty Cleaning, Polishing, and Sanitation Preparations
3679	Electronic Components, NEC	3721	Aircraft
2899	Chemicals and Chemical Preps., NEC	3531	Construction Machinery and Equip.
3674	Semiconductors and Related Devices	2834	Pharmaceutical Preparations

NEC= Not Elsewhere Classified

Table 6. List of interviews.

We interviewed each person on this list at least once during the summer of 1996. Individuals are identified here with the company or organization they worked for at the time of the initial interview, but with the high levels of mobility in the industry, it is expected that some have moved since that time.

Houston

1. **Pyramid:** Louis M. Wells, Vice President Engineering
2. **Montell Polyolefins:** C.J. LeBlanc, Plant Manager
3. **SK Biosciences Corp.:** Frank Cristi
4. **Air Products and Chemicals, Inc.:** Bob Martien, Manager of Environmental Affairs
5. **Haltermann Inc.:** Simon Upfill-Brown, President and CEO

Austin

1. **3M Corporation:** Robin Pollock
2. **Advanced Micro Devices:** Kevin E. Picco, Senior Product Marketing Engineering
3. **Applied Materials:** Erwin Carroll, General Manager
4. **Crystal Semiconductors:** Nav Sooch
5. **Dell Computers:** George Huntington
6. **Ross Technology:** Trevor S. Smith, Vice President of Product Design
7. **National Instruments:** Jhon Lay, Manager, Engineering Process and Support
8. **Motorola:** Claude Moughanni, Manager
9. **DTM Corporation:** Michael Ervin, Vice President, Engineering, Development and Manufacturing
10. **VLSI Technology:** Khalil Shalish

Fort Worth

1. **Bell Helicopter Textron:** Lawrence E. Frase, Business Planning Manager
2. **Lockheed Martin Tactical Aircraft Systems:** William Bullock, Executive Vice President

Dallas

1. **Decibel Products:** Peter Milandt, President
2. **Northern Telecom:** Graham P. Strange, Vice-President Network Marketing
3. **RF Monolithics, Inc.:** Sam L. Densmore
4. **Texas Instruments:** George A. Consolver, Director, TI Stràtegy Process

San Antonio

1. **VLSI Technology:** Dick Watson, Equipment Engineering
2. **Fairchild Operations:** Herbert K Langthorp, Vice-President Operations

Table 7. Number of high-technology manufacturing establishments.

MSA	DTM[1]	Percentage	Sample[2]	Percentage
Austin	342	7.6	39	10.4
Dallas	1,371	30.7	100	26.7
Fort Worth	630	14.1	52	13.9
Houston	1,827	40.9	150	40.1
San Antonio	295	6.6	33	8.8
Total	4,465	100	374	100

[1] DTM = *Directory of Texas Manufacturers,* 1995 edition. Based on Markusen et al.'s (1986) 100 4-digit high tech SIC codes (see Table 1).

[2] Based on 5 top high tech 4-digit SIC codes in each metro area by number of firms and volume of employment (see Table 4).

Appendix D
Japanese Manufacturing Establishments in Texas

Aromat Corporation
Mr. Ken Ptaff
850 East Arapano Road
Richardson TX 75081-----
214/235-0415

Kobelco America, inc
10515 Harwin Drive Suite 139A
Houston TX 77036-----
713/981-4050

AERA Corporation
8601 Crosspark Drive 3100
Austin TX 78754-----
512/339-7100

AVX Corporation
Mr. Matt Vogel
Suite 807, 1701 Greenville Avenue
Richardson, TX 75081-----
214/669-1233

Action Stainless, Inc
Mr. Hal Oxspring
6922 La Paso
Houston YX 77087-----
713/640-2823

Allied Apical Co.,Inc.
Mr. Takeoka
6161 Underwood Road
Pasadena TX 77507-----
713/474-1879

America Taisho Electric Corporation
Mr. Takumu Osao
1200 Golden Key Circle Suite 300
El Paso TX 79925-----
915/595-3697

American Yazaki Corporation
Mr. Keith Daubt
12 Leighfisher
El Psao TX 79906-----
915/778-5373

Anelva Engineering Corporation
Suite 199 800 East Campbell Road
Richardson TX 75081-----
214/437-4671

Arai North America
Suite 460,12801 North Central Expressw
Dalls TX 77002-----
713/654-7101

Awaji USA, Inc
Mr. Eiji Mio
Suite 300 east, 4801 Woodway Drive
Houston TX 77056-----
713/439-0333

Calsak Corporation
Mr. Hal everton
6819 Fulton St.
Houston TX 77022-----
713/699-0501

Canon U. S. A., Inc,
Mr. Doug Johnson
3200 Regent Boulvard
Irving TX 75063-----
214/830-9600

Cantex.Inc.
2101 S. E. 1st St. P.O. Box 76
Mineral Well TX 76068-----
817/235-3344

Chickasha Cotton Oil Co.
Site 550. 6100 Western Place
Fort Worth TX 76107-----
210/423-6540

Chickasha cotton Oil Co.
P. O. Box 532379
Harlingen TX 78553-----
10/423-6540

Chusei U.S.A. Inc.
12500 Bay Area Blvd.
Pasadena TX 77507-----
713/474-6540

Colin Medical Instruments Corp.
5850 Farinom Drive.
San Antonio TX 78249-----
210/690-8800

Cryco Quartz Inc.
8107 Altoga Dr.
Austin TX 78724-----
512/926-8931

Dianal America Inc.
9675 Bayport Blvd.
Pasadena TX 77507-----
713/474-7777

Disco High Tech America
Mr. Garg Harris
900 East Park, Suite 150
Plano TX 75074-----
214/423-4798

E. K. Fasteners, Inc
Mr. Ken Lawson
Suite 100, 4300 Pinetimbers Lane
Houston TX 77041-----
713/462-2100

Ebara Internationl Corporation
Mr. Clyde Marks
Suite 344 4545 Pinetimbers
Houston TX, 77041-----
713/820-7850

Elcom. Inc.
20 Butterfield Trail
El Paso TX 79906----
915/779-0077

Electroluminescent Technologies Co.
5524 Bee Caves Road Building M
Austin TX 78746-----
212/327-9801

Epson America
Suite 2029, 1950 Stemmons Freeway
Dallas TX 75207-----
214/746-3260

Eval Company of America
11500 Bay area Blvd..
Pasadena TX 77507-----
713/474-9111

Fanuc USA Corporation
Mr. Jimmy Shintani
1010 Richcrest Drive
Houston TX 77060-----
713/876-3530

Firestone Synthetic Rubber & Latex
Mr. Colien Riengle
P. O. Box 1269.1006 Farm road
Orange TX 77630-----
409/883-1776

Fujikoki America. Inc
Mr. Geoge Lambert
4040 Bronze Way
Dallas TX 75237-----
214/333-4266

Fujinon inc
Mr. Dave Waddell
2001 Midway Road #114
Carrollton TA 75006-----
214/385-8902

Fujitsu Network Systems. Inc.
Mr. Inoue
2801 Telecom Pkwy..
Richardson TX 75082-----
214/690-6000

Fujitsu-ICL System Inc.
Mr. Rod Powell
5400 LBJ Freeway, 3450
Dallas TX 75240----
214/982-8400

Geo Space Corporation
Mr. Ohya
7334 N. Gessner
Houston TX 77040-----
713/939-9700

Global Octanes Texas L. P
Mr. James, K. Cole
2621 Tidal Road
Deer Park TX 77536-----
713/478-4086

Glory (USA), Inc.
Mr. Joe Collins
Suite 103, 1600 North I-35 East
Carrollton TX 75006-----
214/323-0411

Gould Inc.
Mr. Jerry Doon Hecker
2410 Highway 281 N. P.O. Box 729
Marble Falls TX 78654-----
210/693-3522

Hitachi Semiconductor, Inc.
6431 Longhorn Dr.
Irving TX 75063-2738
214/518-1501

Hosokawa Micron Internationl, Inc
6110 South 42nd Avenue
McAllen TX 78503-----
512/682-4557

INX International Ink Co.
Mr. David Corona
85 Oates Road #2
Houston TX 77013-----
713/672-5670

ISK Biotec Corp.
2239 Haden Rd..
Houston TX 77015-----

Iwatsu America, Inc.
Mr. Davis Carissimi
8722 Royal Lane
Irving TX 75063-----
214/929-0242

K-Bin Inc.
Mr. Danis Dodgen
5616 Highway 332 East
Freeport TX 77541-----
409/233-6610

Kanda Telecom Inc
Suite R, 1807 Braker Lane
Austin TX 78758-----
512/453-8562

Kaneka Texas Corporation
6161 Underwood Road
Pasadena TX 77507-----
713/474-7084

Kikkoman Internationl, Inc
Suite 205, 1440 W. Mokingbird Lane
Dallas TX 75247-----
214/516-4207

Kimmon Quartz Ltd.
Mr. Takashi Hirosawa
5757 N. Riverside Drive
Fort Worth TX 76137-----
817/232-3995

Kohl & Madden Printing Ink Corp.
8900 Premier Row,
Dallas TX 75247-----
214/638-5560

Konica Business Machines USA, Inc
24 Greenway 800
Houston TX 77046-----
713/871-9392

Konica Business Machines USA, Inc,
Mr. Lorita Boyd
Suite 300, 12900 Senlac Drive
Dallas TX 75234-----
214/247-2471

Kuraray America
Mr. Tomida
11500 Bay Area Boulevard
Pasadena TX 77507-----
713/474-9111

Lamesa Cotton Oil Mill
P. O. Box 421
Lamesa TX 79331-----
806/872-2166

Master-Halco, Inc.,
Mr. Tim Taner
8008 C. F. Hawn Freeway
Dallas TX 75217-----
214/391-1126

Matheson Gas Paroductsd. Inc.
P. O. Box 969.1290 West Fairmont Parkw
La Porte TX 77572-----
713/471-2544

Maxroy Corporation
1360 Post Oak Blvd. Suite 1590
Houston TX 77056-----
713/621-5579

Mistui Petrochemicals
Mr. Yutaka Haneda
1000 Louisiana St. Suite 5690
Houston TX 77002----
713/236-627-

Mitsubishi Caterpillar Forklift
Mr. Tetsu Okuno
2011 W. Sam. Houston Pkwy.N.
Houston TX 77043-2421
713/467-1234

Mycom Houston Enterprises Inc.
Mr. Hank Noguchi
4327 Centergate Dr.
San Antonio TX 78217-----
210/599-4518

NTN bearing Corporation of America
2200 Century Circle
Irving TX 75062-----
214/721-0110

Nagaoka U.S.A. Corp.
Mr. Yoshi Nagaoka
Northwoods Industrial Park Central 119
Houston TX 77401-----
713/937-1590

Nippon Pigment inc.
10900 Strang Road.
La Porte TX 77571-----
713/471-4777

Nisseki Chemical Texas. Inc.
16856 Royal Crest Drive.
Houston TX 77058-----

Noltex L. L. C.
12220 Strang Road.
La Porte TX 77571-----
713/937-5800

Olympus America, Inc
Mr. Ray Duram
3131 West Royal Lane
Irving TX 75063-----
214/556-9697

Oyo Geospace Instruments, Inc.
Mr. Arnold Pater
9777 W. Gulfbank 10
Houston TX 77040-----
713/937-5800

Parana Suppliers Corp.
11540 Pellicano
El Paso TX 79936-----
915/593-0050

Phillips Sumika Polypropylene Co.
2625 Bay Area Alvd. Suite 590
Houston TX 77058-----
713/244-3088

Photronics
Mt. Mike Yomazo
P. O. Box 655012-MS943 13536 N. Exp.wa
Dallas TX 75243-----
214/995-6275

Precision Rolls Inc.
4205 McEwen Road.
Farmers Branch TX 75244-----
214/386-6700

Primo Microphones, Inc.
Mr. Allan Taler (Mfr Mg)
1805 Couch Dr..
McKinney TX 75069-----
214/548-9807

Quartz International Corporation
Mr. Mark Rowe
1625 Crescent Circle. Suite#112
Carrollton TX 75006-----
214/323-0442

Reichhold Chemical. Inc.
Mr. Denis Atchrson
1503 Haden Rd.
Houston TX 77105-----
713/453-5431

Sanden International USA, Inc.
601 S. Sanden B,vd..
Wylie TX 75098-4999
214/442-8400

Sanden International USA, Inc.,
10710 Sanden Drive..
Dallas TX 75238-----
214/349-3030

Satake ESM International Inc.
9800 Townpark Dr.
Houston TX 77036-----
713/981-9185

Shinko Electric America, Inc
Suite 825 1701 N. Greenville Avenue
Richardson TX 75081-----

Shinko Wire America. Inc.
Mr. Yoshi Tanaka
11020 Tanner Rd.
Houston TX 77041-----
713/937-7178

Shintech inc.
5618 Highway 332 East
Freeport TX 77541-----
409/233-7861

Sony Magnetic products. Inc.
5819 Riverside Dr.
Laredo TX 78041-----
713/937-9185

Sony Microelectronics Corp.
1 Sony Place
San Antonio TX 78245-----
210/681-9000

Sun Graphic Technologies. Inc.
Mr. Morio Hirota
14801 Trinity Blvd.
Fort Worth TX 76155-----
817/355-9600

Sunrise Industry America. Inc.
Mr. Igarashi
9600 Plaza Circle
El Paso TX 79927-----
915/859-1199

Swift Adhesives Inc.
4920 Gold Steet.
Dallas TX 75237-----
214/946-2940

TKS (U.S.A.), Inc.
Mr. Steve Hashimato
1201 Commerce Drive
Richardson TX 75081-----
214/437-4466

Teccor Electronics. Inc.
Mr. Lapierre
1800 Hurd Dr.
Irving TX 75032-4385
214/580-1515

Texas Arai.Inc.
Mr. Atten
8204 Fairbank N. Houston Road.
Houston TX 77064-----
713/937-1800

Texas ISA. inc.
MR./MS. Sami Sato
14825 St. Mary's Lane Suite 250
Houston TX 77079-----
713/493-9925

The Graphic Technology Corp.
2113 Wells Branch Pkwy
Austin TX
512/990-9700

Toshiba International Corp.
Mr.Yohida Toshio
13131 West Little York Road.
Houston TX 77041-----
713/466-0277

Toyoda Machinnery USA Inc.
Mr. Michael D. Goodger
Suite 130, 16801 Greenspoint Drive
Houston TX 77060-----
713/875-4450

Tri- Gas Inc,
Mr. Olsen
4545 Fuller Drive Suite 200
Irving TX 75038-----
214/650-1700

U. S. Ink
Mr. Reichel
12010 Corporate Drive.
Dallas TX 75228-----
214/650-1700

United Technologies Furukawa Corp.
Mr. Debe Stanks
6070 Gateway East Suite 316
El Paso TX 79905-----
915/779-3704

VAM PTS Company
Mr. Hammond
19210 Hardy Road
Houston TX 77073-----
713/821-5510

Vie de France Bakery Yamazaki,Inc.
Mr. Rutledge
2314 Mrytle Spring Ave.
Dallas TX 75220-2418
214/556-0226

Western SLiyho Tech Plant
US Hwy. 69 North
Jackspnvile TX 75766-----

Western Stress, Inc.
1101 Richmond Av. *800
Houston TX 77075-----
713/991-442

Xetel Corporation
Mr. /Ms. Angela Decaro
2525 Brockton Dr.
Austin TX 78758-----
512/834-2266

Zeon Chemical Texas Inc.
11235 Choate Road.
Pasadena TX 77507-----
713/474-9693

Zexel USA Corp. Texas Division
MR. Price
1102 W. N. Carrier Pkwy
Grand Prairie TX 75050-----
214/641-7000